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THE

AMERICAN

JOURNAL OF SCIENCE.

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THIRD SERIES.

VOL. XLII.—[WHOLE NUMBER, CXLII.]

No. 248.—AUGUST, 1891.

WITH PLATES II–IX.

NEW HAVEN, CONN.: J. D. & E. S. DANA.
1891.

TUTTLE, MOREHOUSE & TAYLOR, PRINTERS, 371 STATE STREET.

Published monthly. Six dollars per year (postage prepaid). $6.40 to foreign subscribers of countries in the Postal Union. Remittances should be made either by money orders, registered letters, or bank checks.

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Three Experienced Collectors have devoted their time during July to securing new supplies of minerals for us.—Mr. Atkinson of our firm has been in Europe, Mr. Niven of our firm in Mexico, and our regular collector has been at work in the most promising Colorado localities. It is not surprising, therefore, that we can announce this month as having witnessed the receipt not only of the *largest* accessions ever made to our stock, but probably the *finest* also.

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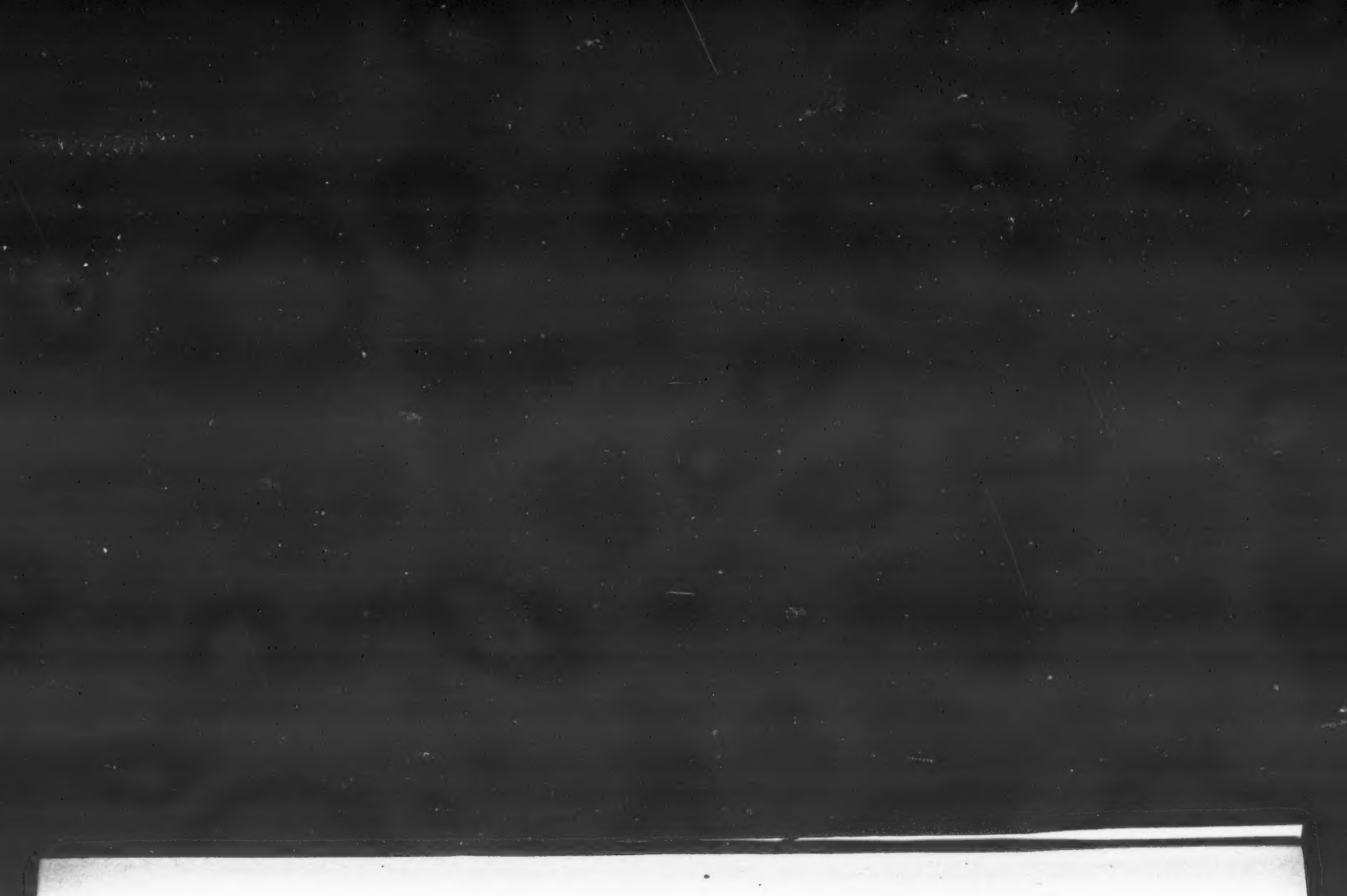


THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

ART. X. — *Some of the features of non-volcanic Igneous Ejections, as illustrated in the four "Rocks" of the New Haven Region, West Rock, Pine Rock, Mill Rock and East Rock;* by JAMES D. DANA. With Plates II to VII.

THE observations on the igneous ejections of the New Haven region here recorded and discussed were mostly completed during the years 1879 and 1880, shortly after the publication (in 1877) of a detailed topographical map of the region by the U. S. Coast and Geodetic Survey, made under the special direction of R. M. Bache. As this map is on the large scale of $\frac{1}{10000}$, or about $6\frac{1}{3}$ inches to the mile, and has 20-foot contour lines, it afforded a very convenient basis for the record of geological facts.

A reduction of a portion of this map to a scale of two miles to the inch, is presented on Plate II.* Excepting the hills in the southwestern corner of the map, its whole area, even that of the New Haven plain, is underlaid by the Jura-Trias Red-sandstone formation. (The excepted hills are part of the border of metamorphic schists that bounds the Jura-Trias region

* This map is a portion of Plate II in the writer's paper on the "Phenomena of the Glacial and Champlain Periods about the mouth of the Connecticut Valley, or the New Haven Region" (This Journal, xxvii, 113, Feb. 1884). The limit of the New Haven plain is marked by a dotted line at the base of the hills, and the contour-lines over it are omitted, the heights instead being given after a special survey. The small nearly circular depressions marked on the map represent "Kettle-holes." The New Haven plain was of river-flood origin and it is presented on the map with the outlines and height unaltered by the gradings for road-making, and by the making of mill-dams; and hence the map is a map of the region of New Haven before 1640, as stated in its title.

on the west.) The map shows the positions of the four trap ridges—more strictly trap-and-sandstone ridges—West Rock, Pine Rock, Mill Rock and East Rock, and gives their heights above mean tide. These rampart-like elevations are now two to three miles from New Haven Bay; but they bear evidence of having been for a time the headlands of a much larger bay.

The ridges are part of the Jura-Trias Mountain-range of the Connecticut Valley. (1) East Rock and West Rock are like the other north-and-south ridges of the range in their form, structure and direction, and West Rock ridge after a course of seventeen miles, dies out just where the higher trap ridges of the Mt. Tom line commence, showing an interlocking with the rest of the system. (2) They consist of Jura-Trias sandstone with an intercalated sheet of trap (as the igneous rock is popularly called). (3) The sheet of trap in the ridges has a rising inclination westward, or a dip eastward, like the associated beds of sandstone, the liquid rock having been extruded from a fissure or fissures situated somewhere to the eastward. (4) As a consequence of these common features, denudation by water and ice has given to the New Haven ridges the features typical of the range,* namely, a steep western front, consisting of sandstone below and the harder trap above, a top of bare trap, and eastern slopes of sandstone, that is of the overlying sandstone.

From such common features the inference as to a common method of origin is natural. Still, as Professor Davis claims, it needs also other support for acceptance.

We note also (4) that these Rocks are situated at the southern extremity of the Jura-Trias Mountain-range; for the Connecticut Valley and its Jura-Trias beds do not extend over Long Island. Instead of this, Long Island pertains to an east-and-west system of mountain-structure. Whether nearness in position to this east-and-west range has occasioned any of the features of the Rocks is an interesting question for consideration.

1. Summary of the principal facts and conclusions.

The facts.—The facts relate to the sandstone of the New Haven region as well as the trap; for the sandstone was broken through to give exit to the liquid trap, and it broke as such a sandstone would break.

(1) The sandstone, as the rock is comprehensively called, varies from fine-grained to coarse, and beyond this, to a fine

* In the writer's paper on the Geology of the New Haven region of 1869, (Trans. Conn. Acad. Sci., ii. 4. 1870), he observes that "the sandstone mass with its intersecting dikes of trap constituted the block out of which the future New Haven region was to be carved by various denuding agencies."

and coarse conglomerate, even cobble-stone-gravel conglomerate. When fine-grained and shaly it is not a firm laminated rock, but divides or crumbles readily to thin chips. The more massive kinds are usually traversed with fractures; and none has much firmness except where consolidated by heat from the trap-ejections, or the hot vapors produced thereby. Consequently, fissures made though the formation should have great irregularities, from irregular fracturing and the tumbling into them of masses of sandstone and large sections of their walls.

(2) The thickness of the sandstone intersected by the fissures over the center of the New Haven region was at least 3000 feet, as proved by borings at a point half way between the bay and the west end of Mill Rock. Along the West Rock line the depth was probably less, as this ridge is within a mile and a half of the western metamorphic limit of the Connecticut Valley of Triassic time. Beneath the sandstone the fissures came up through underlying crystalline rocks, in which they would probably have great regularity in course, width and continuity.

(3) When the heat from the trap, or the hot vapors generated by it, consolidated the sandstone, it generally made hard, durable rock of the coarser kind, but left the finer beds, alternating with the coarse, fragile and chip-making; and this was so, apparently, because hot vapor penetrates most easily the coarser beds for the cementing work. The heat through the penetrating vapors, generally discharged more or less completely the color of the beds it consolidated, producing an ash-gray and brownish shade; made in them steam tubes with blanched walls; produced blotches of impure chlorite, or epidote, and crystallizations of hematite and epidote, and less commonly garnet. But the finer beds that alternate with the coarse commonly retain, except perhaps for a few inches, their red color, and even have it deepened to a dark purplish red—as if by the reduction of some of the red coloring matter (oxide of iron) to magnetite. Moreover, the sandstone often loses all the old bedding. These varying effects from the heat have added much to the original irregularities of the beds.

(1) Of the four Rocks, East and West belong to the prevailing north-and-south system, as already stated; the other two, Pine Rock and Mill Rock, to a transverse system.

(2) In East Rock and West Rock the sheet of trap made by outflow from the opened fissure or fissures has a length westward of 100 to 500 yards.

(3) The supply fissure, or its filling, the dike, descends beneath the eastern slope with a large eastward pitch: the angle of pitch in the case of East Rock being about 50°.

(4) In Pine Rock and Mill Rock, the trap is in *dikes*, there being no evidence of any outflow. Yet these dikes have in some of the outlets the great breadth of 150 to 300 or more feet.

(5) The pitch of these dikes is to the northward; and its angle 18° to 40°—both characters of unusual interest.

(6) Although neither East Rock, Mill Rock nor Pine Rock has a length exceeding a mile and a half, each has three or four distinct outlets of trap, separated by intervening sandstone; moreover, there is wide diversity between the Rocks in the form and arrangement of these areas of extruded trap, as the map illustrates.

(7) The trap of the several ridges, according to examinations by E. S. Dana, is true doleryte, free, or nearly so, from chlorite and other evidences of interior alteration, and not at all vesicular.

(8). Columnar fractures give the rock a rudely columnar structure, in which the half-defined columns are four to eight feet in diameter. In the west fronts of the north and south ridges the rude columns have usually an inclination nearly at right angles to the mean dip of the associated sandstone—according thus with the usual rule: perpendicular to the cooling surfaces. But among the columnar fractures, whatever the inclination of the columns, that plane of fracture or joint which is transverse to the sides of the dike or trap-mass and nearly vertical is the most strongly developed, and consequently the trap often cleaves into nearly vertical plates or laminæ of great extent, much like a laminated rock. There usually is also a second easy cleavage-direction, nearly at right angles to the former so that rectangular columns sometimes come out with great prominence.

(9). The outflows of trap have a floor either of an inclined layer of the sandstone or of edges of the upturned layers.

The principal conclusions.—(1). The igneous eruptions of the New Haven region took place after the sandstone had been upturned; that is, after the evolution of the Connecticut-valley mountain-range in this part of the valley had made great progress.

(2). None of them were volcanic eruptions, for there was no center of action, no pericentric discharge of volcanic materials.

(3). In the outflows from the fissures (those of East and West Rock) the liquid trap did not escape into the open air and spread over the surface, but entered between layers of the sandstone.

(4). Moreover the flow was not by gravity into spaces that had been previously made, but a forced flow that opened

spaces or chambers for its occupation, the liquid rock thus lifting the overlying sandstone as long as the discharge was continued. By such means the sheets of liquid trap attained, in some cases, a thickness of 300 or more feet. This forcible opening and filling of a chamber in the sandstone by the upthrust lavas, is a *laccolithic* process, it according with that of the typical laccoliths ably studied out and described by Gilbert.*

(5). The intrusion of the flowing rock between the sandstone layers took place at comparatively shallow depths, where the pressure of the rock was not too great to prevent it.

(6). It was favored, in each case, by the fact that the oblique fissure supplying the lava was inclined in the same direction with the layers of the uplifted sandstone—both inclining westward, the dip being eastward.

(7). The termination of a fissure in several outlets, exemplified in three of the Rocks, was largely due to the great inclination and depth of the fissures opened through the weak upturned and faulted sandstone, and thence to great downfalls of the hanging wall. The same cause led to irregularities in the width and forms of dikes, and influenced the outlines and surface-features of outflows.

(8). The course and dip of supply-fissures was not determined by the foliation or bedding of the schists underneath the sandstone.

2. Special facts from the several Rocks illustrating the above conclusions.

The ridges, Pine Rock and Mill Rock, containing simple dikes are first considered, and then East Rock and West Rock, which include dikes and outflows from them.†

1. PINE ROCK.

The general form of Pine Rock is shown on Plate II, and still better on the following larger map.‡ It is only three-fourths of a mile long and trends N. 67° E., or east-northeast. This small ridge has three, perhaps four, independent outlets of trap, A, BB′, CC′ and D. The first, at the west end, is a small dike 15 to 20 feet wide, trending north 20° west, and traceable for 220 feet. It dips eastward 25°, and thus proves

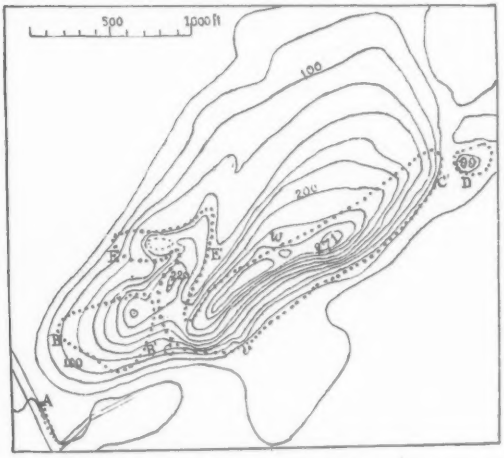
* Geology of the Henry Mountains by G. K. Gilbert, 4to, 1877.

† In justice to Percival, the author of the Report on the Geology of Connecticut of 1842, it should be here stated that there is scarcely an outlet or area of trap mentioned beyond which is not recorded on his map or described in his Report.

‡ The contour lines on this map, and also those on that of Mill Rock on page 87, are copied from the Bache Coast Survey map.

that it is not an outlier of West Rock, but part of the Pine Rock group. The other three are, more evidently, outlets from one great fissure. The width of the larger mass, CC′, is about 300 feet; and it is therefore one of the widest of dikes. The dip of the dike is 50° to 55° northwestward. This inclined

1.



Map of Pine Rock. Heights reckoned from high-tide level. Areas of trap with dotted outline.

position (35° to 40° from a vertical) is given the dike in fig. 2, in which D I K E represents a section of it between its sandstone walls before denudation, and *d i* K E, the same through the

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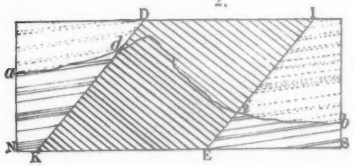

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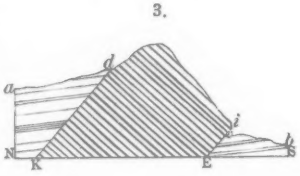


highest point of the Rock as it now is—or was before recent quarrying. The cross-lining gives the direction of the columnar fractures. The other figure, fig. 3, is a section through *v* on the map, where the removal of the sandstone of the southern wall (*v*, in the section) has left a depression called the *Cave*. (The sandstone of these sections is now concealed by the debris, and outside of this by the Terrace formation.)

The southern wall of the dike is the roof of the cave; the rock has the fine texture and fissured surface usual where it cooled in contact with the sandstone. Just above the cave,

4.

Inclined columns of Pine Rock, above the "Cave."

where the exterior is removed, the surface is made up of the ends of rude columns. A profile view of these inclined columns from a point just south is shown in fig. 4.*

At *w*, (see the preceding map) the *north* wall of the inclined dike is uncovered for a height of 50 feet, the sandstone having been carried off by the glacier.†

At the eastern extremity of Pine Pock (near C′), the trap of the north wall may be seen in contact with hard-baked sandstone. In the large quarry just south, the rock exhibits finely the transverse lamination crossing the dike—referred to on page 82. The laminæ incline 10° to 15° to the eastward, the dip being 80 to 85° to the westward. The surfaces of the plates are usually yellowish-brown with limonite for scores of feet from the summit, owing to the waters that penetrate from the surface downward and oxydize the iron of the rock; but in the transverse joints or cracks, which are less accessible to the waters, there is usually a coating of stilbite and sometimes

* From a photograph by G. N. Lawson, of the class at Yale of 1890; taken in December, 1890.

† The shaping of the northern slopes of the Pine Rock ridge is a part of the same work of the ice; and the trend of the mass, like that of Sachem's Ridge, (Plate II), indicates the direction of movement of the glacier. The same is true for the northern slopes of Whitney Peak and Indian Head.

of other zeolites, as chabazite, analcite, heulandite.* The dike has a few transverse courses of fracture containing prehnite and occasionally apophyllite, but no longitudinal have been observed.

A sandstone ridge connects A and BB′, in which the rock is hard, and has the strike N. 40°–45° E., and the dip 45° S., becoming N. 30° E. and 30° to 35° in dip more to the west. It is mostly a coarse sandstone; but some layers contain stones 4 to 5 inches in diameter.

Origin of the Features of the Rock.

The existence of so many outlets of trap in the small space, and the irregular forms of the areas are unusual facts. BB′ is short, broad and blunt, shield-shaped; and CC′, is duck-like in shape, the irregular bosses at the northwest end (EE′) making the neck and head. These bosses are not in the line of the dike, and must be due to a local catastrophe. In view of the great inclination of the fissure, and its depth of 2000 to 3000 feet in the weak sandstone, a caving in of some part of its northern or hanging wall would be of extreme probability. Such a catastrophe would account for the stoppage of the outflow and the separation thus of BB′ and CC′; and such a stoppage of the up-thrust lavas would explain their escape by one or more extemporized outlets, and for the actual position of the apertures on the *north* side of the fissure; and thereby for the making of the bosses. The obstructed lavas of the fissure may also have found exit in the western dike, A.

The trap-mass D is possibly a result of a second smaller catastrophe of like character; but its separation from CC′, may be a result of erosion.

Another consequence of the great inclination of the fissure is the exposure of the dike of heavy trap to degradation through the removal of the supporting sandstone on the south side. Such undermining has produced the steepness of the southern front. And sea-shore *waves* or breakers were probably the chief agent—the shores being those of the broad center, or a central arm, of the New Haven Bay.

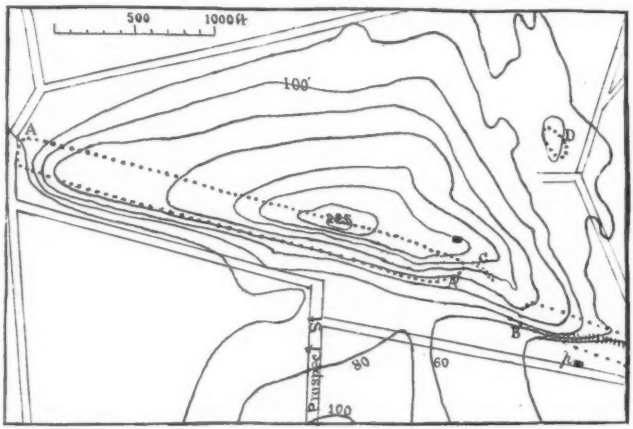
2. MILL ROCK AND THE WHITNEY RIDGE.

Mill Rock is one mile distant from the east end of Pine Rock. Its length to Whitneyville or Mill River, is four-fifths of a mile. This small area, as is seen on Plate II, and better in the following larger map, has four independent outlets of trap—

* The surface of the crust of zeolites is frequently tinged with the red iron oxide—which is a probable indication of heat as high at least as 200° F. during the formation of the minerals.

the western, AA′, the eastern, BB′; north of the gap between these, a short narrow dike C, and farther north, the isolated area, D. The width of the first, AA′, (as measured at its west end) is 200 feet; of the second, 140 or 150 feet; of the third, 1 to 10 feet; of the fourth, 50 feet, the length being 150. The mass BB′ continues to Mill River where the surface of the country declines to tide level. But the trap does not stop here; it crosses the river and extends on eastward, with an increased width, 180 feet, to the summit of Whitney Peak. The Whitney Peak dike belongs therefore to the Mill Rock region, although topographically part of the East Rock area. The trend of the Whitney Peak portion is S. 68° E.; of AA′, S. 78° E. The mean course for the whole series to the summit of Whitney Peak is about S. 72° E.

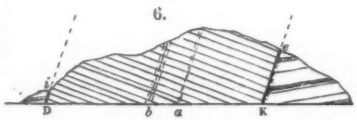
5.



Map of Mill Rock, excepting its eastern extremity. Trap areas with dotted outlines.

The dip or pitch of the main dike is about 72° to the northward, or 18° from the vertical. This inclination and the course of the columnar fractures are well exhibited at the west end of the dike, A, and are represented in figure 6.

6.



Section of Mill Rock, west end.

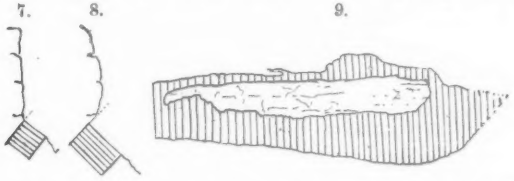
Besides the columnar fractures at right angles to the walls, there are also longitudinal fractures in interrupted lines, parallel to the walls. Two are seen at the west end of the Rock and are indicated in the above figure. They are now mineral veins. The more south-

ern one, *a*, contains chiefly prehnite, with traces of copper ore, and the trap along its course is solid or little altered. The other is situated about half way between the sides. It contains abundantly the very hydrous mineral laumontite and the trap along it is decomposed; it contains also impure chlorite, and is fragile for a breadth of six to ten inches. A similar laumontite vein, but nearer the north wall of the dike, is seen at Whitneyville, and also in the trap of Whitney Peak.

The junction of the Whitney Peak part of the dike with BB′ takes place in the bed of the stream at Whitneyville, and is not now exposed to view owing to the dam and the buildings below it.*

The level of the trap beneath the dam is but a few feet above and below tide level. The height of the Whitney Peak dike increases eastward; first by a sudden rise of 100 feet, and then more gradually in the last 500 yards to 280 feet. Whitney Peak has a bold front to the eastward with sandstone at its base showing a sudden stoppage of the fissure in that direction; and at the same place it widens southward—not by overflow, as the precipitous eastward front and the depth of the trap shows, but through the opening of a transverse fissure. The Rock has a steep wall 70 to 80 feet high, on the north side of the summit for nearly 100 yards; but this is due to the removal of the sandstone by glacier action, exposing the north wall of the trap dike.

The narrow dike C is about 110 feet long. It is situated in the face of a bluff of sandstone; and from the evidences of heat in the hardness of the rock, its mottled and light gray color in places, its steam tubes, and epidote, it is plain that the ejection determined the resisting power of the sandstone against denuding agencies. The following figures represent



two cross sections from the western half, and a map of the last 40 feet of the eastern half. At 65 feet the outflow is divided,

* To the fact of this continuation I have recent testimony from Mr. Eli Whitney, who has superintended the constructions made there during the past forty years. Besides mentioning that the dam was built along the junction of the trap and sandstone, he says that below the dam for some distance, there is trap rock only, no sandstone outcropping there to his knowledge.

The gun factory at Whitneyville was established there by his father, the inventor of the cotton-gin, in 1798, for the manufacture of muskets for the United States Army.

a narrow stream of trap (fig. 9), coming out above a layer of the sandstone 5 to 6 feet thick, the main part of the dike appearing below. This envelope of sandstone by trap continues for 30 feet, when the two parts come together again. The depth at which the side stream goes off from the main dike is not known. The inclination of the dike is mostly 25° to 28° (fig. 7) from a vertical, but at 45 feet from the west end it becomes 40° (fig. 8), and 10 feet beyond this, 30°.

The sandstone of the Mill Rock region is of all degrees of coarseness up to cobble-stone conglomerate; and no distinction is observable between that of the west and east ends.

Origin of the Mill Rock features.

The subdivision of the trap into its four masses may be explained in the same way as that in the Pine Rock area. A downfall of the northern sandstone wall of the fissure, the hanging wall, would account for the separation of AA′ and BB′. Further, the obstruction thus occasioned to the great ascending stream—its width 150 to 200 feet—would have forced open passages to the surface for the discharge of the liquid trap, and thus may have been produced the small dike C, situated near the fissure wall, and the remoter mass D. The irregularities of the little dike C, and the situation of both C and D to the north of the line of the dike, accord with this idea of a downfall of a part of the northern wall. The liability to such a catastrophe in a wall made of the rude sandstone 3000 feet or more high, and having a large inclination, was augmented in both Pine Rock and Mill Rock by the tilted position and faulted state of the sandstone. The beds had already received their eastward dip of 15° to 25°, and breaks and faults innumerable that had been made in the adjustment to the new tilted position; it was therefore a tottlish structure overhanging a profound abyss. The fact here introduced that the eastward pitch of the sandstone was given it before the ejection of the trap is sustained by facts reported beyond. But an argument for it is afforded here: for if this *eastward* pitch were of subsequent origin, then the Whitney Peak end of the system should be the lowest. Instead of this it is greatly the highest; the ridge slopes westward.

It is possible that the fissures of AA′ and BB′ were, from the first, independent fissures to a considerable depth; for they are not in precisely the same line. If this were so, the above explanation, while in the chief points right, would require some modification.

As in Pine Rock, so with Mill Rock but to a less degree, the northward pitch of the dike made it easy of degradation

by sea-shore action. Through such means, beyond doubt, the part of it extending from Mill River westward for 300 yards, was reduced to a width above ground of 40 to 50 feet. This narrowing commences just west of the Pumping House of the City Water Works (*p*, fig. 5), and continues without interruption to the river. It is part of the evidence of a greater New Haven Bay at some former time.

Why the range falls gradually to so low a level at Whitneyville, appears to be explained only on the view that less trap here came to the surface. I have elsewhere shown that it cannot be due to glacial removal. Neither is it probable that fluvial or marine waters have produced it. We have to attribute it to some condition existing or produced in the supply-fissures of eastern Mill Rock and Whitney Peak, at the time they were opened.

Besides the dikes of Pine Rock and Mill Rock, there is another transverse dike of special interest which intersects the West Rock ridge just below the margin of Wintergreen Lake, or about one and a quarter miles north of the southern termination of the ridge and four miles from New Haven Bay. It descends the eastern slope of West Rock in an interrupted ridge, forms part of the southern bank of Wintergreen Lake, sinks to the level of the West Rock surface at the summit, but stands out like a buttress along the steep west front of the Rock. From the last feature I have called it for the past twenty years, the "Buttress dike." It extends south-westward through the metamorphic region of the towns of Woodbridge and Orange to the mouth of the Housatonic—as long since mapped and described by Percival. This dike has a pitch northward, amounting to 25° from a vertical in the part of it intersecting West Rock, but in that through the metamorphic rocks it is nearly vertical.* The strike of the inclined columns in the buttress portion is S. 30–32° E. It is an example of a dike made subsequently to the cooling of another dike, that of West Rock. It has great importance in this connection, since it brings into the Jura-Trias system of mountain-movements a dike intersecting the metamorphic rocks outside of the Connecticut Valley, and one that branches off from the southern or New Haven part of the system.

3. THE EAST ROCK SERIES.

The form of the East Rock area and its position between Mill River and the Quinnipiac, are shown on Plate II. Through

* The rock of the dike is sparsely porphyritic; and the feldspar distributed through it in crystals a fourth to a third of an inch long is anorthite, as shown by G. W. Hawes (this Journal, III, ix, 188, 1875). This character makes it easy to identify the several parts of the dike; it is the only case in which this mineral has thus far been found in the Connecticut Valley trap.

Percival's account of the Buttress dike and its extension southwestward is on page 399 of his Report.

denudation by the sea, rivers and ice, it has lost all of the sandstone formation that may have covered the summit, and for the most part that over its slopes above the 200-foot contour-line. The form of its upper portion is therefore largely that of the trap in its constitution—the hard rock that was most successful in resisting wear. This fact gives special interest to the larger and more detailed topographical map making Plate III, as will appear beyond.*

To the north is Whitney Peak, which has already been described as the eastern extremity of the Mill Rock series. South of this and of a large area of sandstone, are East Rock and Indian Head, one in trap surface, but in fact the result of two independent outflows. To the south of Indian Head is Snake Rock, which also has its large trap mass, but is peculiar in having ridges of hard-baked sandstone that are higher than those of trap. The East Rock areas of trap here referred to are lettered on the map BB′, CC′C″, DD′. Besides these there is a more northern one, lettered AA′, which lies near the eastern foot of Whitney Peak.

The trap-mass AA′.—This northernmost mass, is about one hundred yards long. At its northern end it is only forty feet distant from the trap of Whitney Peak, and it is a question, therefore, whether it is not a part of the latter dike. But it is separated from it by outcropping sandstone, except where the interval is narrowest, and at this point there was until recently drained, a standing pool of water, a pretty good indication that sandstone exists beneath, since trap is commonly too much fissured to hold water or afford springs. Moreover, the mass AA′ has the trend of the East Rock series; and,

* The map of East Rock Park which is the basis of Plate III, was obtained from the Engineer department in New Haven, through the City Engineer, Mr. A. B. Hill. The roads of the Park from the termination of Orange St., around by the north to the summit of East Rock are lettered *F*, and the others *E*. These letters refer to two citizens of New Haven, Henry Farnam and James E. English, who liberally bore the expense of their construction. The topography is in part from the Bache Coast Survey map; but the accuracy of its contour lines was not sufficient for their transfer to the Park map. The heights are reckoned from high tide. The map is indebted to Prof. S. E. Barney, for the determination by leveling of the height of the highest point of East Rock, just south of the monument (358½ feet) and also of other points on its south and east sides, and for that of the junction of the trap and sandstone on the west front near Orange St. bridge (155 feet). The height of the bolt at the Coast Survey Station he found to be 343 feet, and the height of the top of the first step leading to the terrace about the monument, 355 feet. (Prof. Barney's figures are underscored on the map). The circuit road about the summit has a height of 320 to 350 feet; and the nearly parallel road on the east rises from about 216 feet near the quarries south of the summit, to 270 near the junction of the "Farnam drive" and "English drive," and thence declines northward to about 250 where it bends westward. The letters S on the map indicate an outcrop of sandstone in the vicinity of junctions with the trap.

In giving the topography of the Rock, the quarry excavations on the south side above a level of 216 feet are not introduced, it seeming best to represent the Rock in its original form. They are separately mapped on the plate.

besides, ledges of trap along the east side appear to indicate that the supply of liquid rock was from the eastward, like that of East Rock. On this view it is the northern mass of the East Rock series.

East Rock proper.—The trap mass BB′, or East Rock, curves around from N. 25° E., on the north to N. 75° W. at the southwest extremity. Adding to it the Indian Head mass, it ends in an east-and-west dike, and is a complete crescent in outline. It has a bold columnar front, in which the columns incline about 22° from a vertical—the position, being, as is usual, at right angles to the mean dip of the tilted sandstone. A view of the southwest front of the Rock is presented on Plate IV. Plate V illustrates the character and inclined position of the columns, and shows the contrast in the latter respect with Pine Rock.

The upper 200 feet are of trap. The junction of the columnar trap with the sandstone is exposed to view at several points along the front. One such exposure may be seen when crossing the Orange Street bridge. The view in Plate IV, in which the bridge appears in the foreground, has the exposure half way up the front to the right. The height of the junction plane above mean tide at this place is 155 feet. Another is faintly indicated on the same plate directly below the Refreshment House; the height of the junction is there 150 feet. In other exposures of the junction-plane to the north, the height is less and becomes only 85 feet near the Rock Lane bridge; and it is also less to the south being but 132½ feet at B′, the southwest angle of the trap mass. Since the strike of the sandstone of the region is about N. 30° W., the sandstone (or the junction plane) has its greatest height, 155 feet, where the front has this direction; and the bedding of the sandstone in the section for this reason appears to be horizontal. The diminished height to the northward is owing mainly to the exposures being at a lower level on the junction-plane because of the changed direction of the front, it becoming N. 10° E. near Rock Lane bridge. Through this interval the trap retains its thickness of about 200 feet. North of Rock Lane bridge the underlying sandstone is wholly covered by debris, so that the position of the junction-plane is doubtful.

The supply of the trap forming East Rock came up, as the slope of its surface shows, from the eastward; and it continues rising westward to the western and southwestern margin of the summit. The slope from the summit eastward and northward is gradual for about 300 yards, and then it pitches off at an angle of 45° to 50′ along the course of one of its dikes.

The position of the dike, and thereby of the supply-fissure, is well exhibited at *bc*. A bare wall of trap, 50 to 55 feet in

height, descends at the angle mentioned. Since the surface there exposed became solidified against the northern sandstone wall of the fissure, the rock is of fine-grained texture and has an irregularly rifted aspect. The foot of the wall is about 200 feet above high tide, and from it the land, underlaid by sandstone, slopes off gently to the eastward. Since the direction of this wall of trap is S. 15° W., or that of the movement of the ice over this region in the Glacial era, the wall escaped the tearing action of the glacier, and so retains its original surface.

Farther south, along a line from *d* to *e*, there is a similarly steep slope, but it is made of displaced blocks of trap. At its base there is a flat, terrace-like surface, which is near 200 feet above tide level. This steep slope appears hence to have been the course of the wall of another part of the supply-fissure. The flat terrace, although nearly 100 feet wide, is without stones over its surface of either trap or sandstone except in its southern portion, and there occur sandstone in fragments along with trap, and an outcrop of sandstone over trap at S. This fact and the occurrence of a perennial spring in this southern part (at the point toward which the two paths on the map, Plate III, descend) make it probable that the terrace rests on sandstone, and that this sandstone was that bounding on the east, the supply-fissure above referred to.

But there is trap again to the east of this terrace, showing that the lower eastern slopes were supplied from a more eastern fissure. Along from *c* to *d*, the trap of the outer fissure appears to have flowed over and coalesced with that of the inner. Again south of *e*, the distinction of the two fissures cannot be made out. But the fact that the supply-fissures, one or both had a large inclination—not far from 45°—is evident from the very steep slope of the surface.

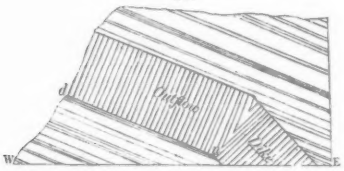
Sections of the dikes of trap are nowhere exposed, and hence we are ignorant of the width of the supply-fissures. Judging from those of Mill Rock and Pine Rock, it may have been 150, 200 or 300 feet; but it was possibly much less.

The Outflows.—In East Rock, the trap which overlies the sandstone along the front, was that of outflows from the fissures westward between layers of the tilted sandstone. The fact that the columns of trap have a position at right angles nearly to the inclined layers of sandstone is believed to be good evidence of this intrusion of the melted trap.

Fig. 10 represents the view that has ordinarily been held with regard to the relative positions of the trap and sandstone. According to it the trap left the dike to flow westward between sandstone layers having a dip of 20° to 25°. A space was opened between the layers of sandstone which the liquid

trap filled. It is plain that this chamber could not have been so opened in advance of the inflow; for the hanging wall of the weak sandstone inclined 65° would have had no support. It is hence evident that the ascending stream of trap, forced

10.



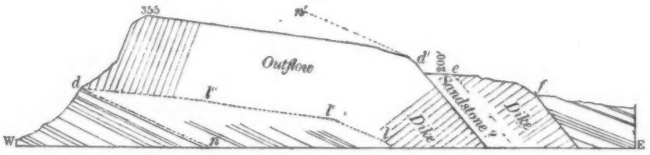
Ideal Section of East Rock before the removal of the sandstone from the summit.

along its course, opened a way between the layers; that a tongue of trap first entered, which would have been partly cooled against the cold rock; but the flow was kept up below this first intruding portion until the trap had all entered, the lifting of the overlying sandstone going on as it needed more space. This lifting would have brought a strain on the sandstone that would have broken the connection between the lifted portion and that either side, to the northward, westward and southwestward. To the question, therefore, how far did the trap flow westward, the conditions reply: to the wall of such a fracture; and it may not have extended many rods beyond the present limit. The sandstone of the western wall has disappeared in the general denudation over the New Haven region, excepting a small part at the southwest angle, where a zigzag path (Z, Plate III) ascends to its top; the height of this sandstone is 185 feet, which is twenty-five feet above the base of the trap where highest to the northward, and fifty feet above that just south at A′. The locality of this sandstone and the zigzag path is seen on the right margin of Plate IV. The sandstone of the northern wall remains to a height of 196 feet at *m*: the sandstone between Whitney Peak and East Rock is what is left of it. The dip of this sandstone at *m*, near the junction, is 30°, in the direction N. 73° E.; and the inclination of the columns of the trap just above is also 30°.

The theoretical section of East Rock in fig. 10 represents correctly the fact of the intrusion of the melted trap between sandstone layers. But since the bottom over which the flow took place is concealed from view, it is not quite certain that the sandstone layer on which the flow began continued to be the floor to its western limit. Moreover, there is a large discrepancy between the pitch of the trap over the summit and that in the section. An actual section of the rock from

east to west (or more exactly E.S.E. to W.S.W. since this is approximately the direction of a transverse diameter) drawn to a scale, fig. 11, throws some light on these points.

11.



Section of East Rock, showing the correct profile.

This section is essentially right in its profile, but more or less doubtful in its interior lines. The height of the upper surface of the outflow where it left the dike at d' is 265 to 270 feet. It was not less than this; for we have this height for the top of the bare, unabraded wall of trap (adding the part of it under the Summer House west of the road). The length of the overflow to the present western front, is, as already stated, about 300 yards. The height of the western brow of trap in the section is 355 feet;* and that of the bottom of the trap in the western front, 155 feet. These are facts; and the divergence here from figure 10 is very great. Further, the mean angle of the trap surface over the summit is 10° instead of 22°, the mean dip of the sandstone. The latter dip is shown in the lines dn; and if the floor had originally this pitch throughout, the thickness of the trap would have been about 450 feet, this being the distance on the scale of the section between dn and $d'n'$, while actually it is only 200 to 210 feet.

The question arises: How was the lower slope of 10° attained, and how the lessened thickness. Are they a result of wear by glacial or other methods; or was the present slope approximately the original slope of the outflow? A large amount of observation over trap ridges leads me to believe that the loss over East and West Rocks by abrasion has been small, probably not over 50 feet. The glacier, as it was shoved along, might easily have torn off columns from the front, but it would have made little impression on the exposed surfaces. Moreover glacial abrasion would hardly have left the highest points of the summit so near the western edge.

If the outline of the summit approaches that of the original outflow, then—d being the lower limit of the trap on the front—a line drawn from d nearly parallel to the summit plane,

* This is the height 80 feet north of the Summit Refreshment House, just west of the road, this being the highest point over this northern half of the summit area.

would probably represent the position of the bottom of the outflow. The line *d l'' l' l* has been drawn on this view. It supposes that the trap, on leaving the dike, passed between two layers of sandstone from *l* to *l'* and that afterward it broke away the layer beneath it and flowed on, either over the edges or surfaces of layers as the conditions favored.

The only spot where a section of the floor or plane of junction of trap and sandstone, is seen, is at A′, the south-southwest corner of the trap-mass, by the road-side. There, for a few yards, the trap *rests on upturned ledges* of sandstone, and not on one continuous layer. The section is too short for any reliable conclusion were it not sustained by facts from West Rock.

The section, fig. 11, also represents the *inner* and *outer* dikes described above, with the intervening (?) sandstone. The doubts with regard to the widths of these dikes and the area of sandstone have already been the subject of remark.

Columns stand out boldly on the steep western front of East Rock. But they have none of the normal forms, for the angle between the most prominent faces frequently approaches a right angle, resulting from a combination of the plane of fracture at right angles to the trap-mass and another transverse. The direction of these planes varies along the course of the Rock on account of the curve in its outlines. At the quarry, on the south side of the summit, at the termination of the zigzag path Z, there is a fine display of broad surfaces in the two directions meeting nearly at a right angle. The courses here are about N. 35° E. and N. 55° W. The surface of one of them for many square yards is covered with rosettes of garnets and scattered minute crystals of magnetite, their faces brilliant in the sunshine. Along the whole western front of the Rock there is a remarkable predominance of planes conforming to its plane through all its changes of direction. This is apparent on Plate IV. and some of the right angles are seen on Plate V.

The upper half of the columnar front (see Plate IV), down to a level of about 220 feet above tide-level, has columns four to eight feet in diameter; below this the size is in general half less; and for the lower twenty feet above the sandstone, they are quite small.

Indian Head.—Indian Head is much like a small edition of East Rock. The length of the outflow is 100 yards; the height 310 feet (313 above mean tide). A section made on the same principle with fig. 11 of East Rock is given in fig. 12.

Indian Head stands quite apart from East Rock. The gap now separating them, where highest, is about 200 feet above high tide, and therefore nearly 160 feet below the top

of East Rock and 110 below that of Indian Head, and probably sandstone intervened for the greater part of this depth; for the two Rocks face one another with steep slopes, as well brought out on the map, Plate III. These continue to be

12.

Section of Indian Head.

steep to the very foot of each, where they approach one another down the eastern slopes. Their bases are here in independent valleys, designated on the map by the letters E and I, separated by a low trap ridge, R, so that East Rock and Indian Head, although the trap extends over the surface of the gap from one to the other, are nowhere united at base. The eastward sloping valley, I, lying at the northeast foot of Indian Head is continued in a westward sloping valley I′, at its northwestern foot, and the two together define its outline. The low trap ridge R, between E and I, although consisting at surface mostly of blocks of trap, has a solid ledge in its lower part. It probably crosses the gap westward; and the Summer House, near 201 on Plate III, may be on its western part. The valley E, at the southeast foot of East Rock, is perhaps, a result of glacial action; but why there should be two valleys side-by-side if erosion made either, is not explained.

The trap of Indian Head rises from the bottom of the small valley just mentioned apparently in two half-separated streams instead of one even stream; but this feature may be a result of erosion. The eastern outline of the trap (see Plate III) is in a line with the eastern of the East Rock trap, indicating that the supply-fissure corresponded in direction with the outer and not the inner of the East Rock courses of fissures. The two Rocks, although alike in features, are to a large degree independent. Abrasion helped to deepen the gap between them, but more by the removal of sandstone than of trap.

Indian Head is peculiar in having a long eastward projection from the southern end. It is described on a following page.

The mode of origin of the trap-masses of East Rock and Indian Head—by a forced flow of lava, opening through its uplifting action, a chamber in the sandstone for its accommodation—entitles the two to be called *laccoliths*. Through degradation, stripping them of the covering of sandstone, they stand side-by-side—a pair of laccoliths.

Snake Rock.—In Snake Rock, a broad mass of trap measuring about 900 by 450 feet in its two diameters lies encased in sandstone. The greatest height of the trap is but 160 feet, and that of the sandstone west of it over 200 feet. The trap covers the eastern slope of the Rock nearly to its foot, thus showing that the supply-fissure was on that side, as in other parts of the East Rock series, and also indicating by its steepness that the fissure was much inclined. At the south end of the Rock, in the yard behind the north corner of the Bassermann house, at a junction of the trap and sandstone, the dip is about 45°; and this is direct evidence as to the inclination.

The area of trap of Snake Rock has on the north the width of that of Indian Head; and the mass may hence owe its increased width northward to an outflow. If so, Snake Rock contains a half-emerged laccolith, its summit exposed, but the western wall of sandstone still standing and overtopping the trap. The sandstone shows everywhere the effects of hot vapors in all their varied forms, and before encroachments were made by a brewery there was a fine display of columnar sandstone in the southwestern bluff.

Origin of the breaks in the East Rock series.

The prominent breaks in the East Rock series are that between Indian Head and Snake Rock, and that separating the small northern area, AA′, from the main East Rock mass, BB′.

The Indian Head and Snake Rock masses, CC′ and DD′, approach one another bluntly within a hundred yards, and the area of sandstone between has parallel sides, as the map, Plate III, shows. In view of the steep pitch of the supply-fissure, a catastrophe to the western or overhanging wall is a most probable explanation of the break between them. The checking of so great a stream for a length of 100 yards might be expected to open escape-ways in some direction. The long eastern tail-like projection from Indian Head, C′C″, is the result of outflow along an east-and-west fissure. The pitch of the fissure, as the position of the trap shows, was about 25° to the northward. Its southern front is steep and rocky, the northern, gentle and grass-covered. It may be that this supply fissure was the escape-way then made, and the trap the part of the stream that would have occupied the interval had no such catastrophe occurred.

The relations of the northern trap-mass of the series, AA′, to BB′ are doubtful. Yet it is probable that the trap of AA′ was ejected from the north end of one of the two East Rock fissures, or lines of fissures. The ledge of very hard sandstone which extends southward from near the south end of AA′, passes by the east side of the dike-wall *bc*; and it probably derived its position and its excessive consolidation and lost bedding to

a catastrophe that closed the fissure for the interval between them, which is only 200 feet wide, yet left it giving out heat, and generating volumes of hot vapors for the consolidating work.

The East Rock masses of trap may therefore be traced to two ranges of fissures. The western was the probable source of the most northern area, AA, and of the summit portion of that of BB′ on East Rock. The eastern, contributed to the lower slopes of East Rock; and also through its continuation southward gave origin to the trap of Indian Head and Snake Rock. But for the accident to the hanging wall of the great fissure, the trap of Indian Head and Snake Rock would have made one continuous mass, and the columnar front of the former might have been continued over part of the present Snake Rock area. The areas of trap in the East Rock series narrow both to the south and the north.

4. WEST ROCK.

The facts and conclusions relating to the West Rock region derive prominent interest from their pertaining to one of the long trap-ranges of the Connecticut Valley region. The area is represented on the accompanying map, Plate VI, from a survey made by the author with chain and hand-level in 1879 and 1880. The 20-foot contour-lines of the steep western and southern fronts of the Rock and the geographical positions are from Bache's Coast Survey map; but the other contour-lines exhibiting the surface features, which required for mapping detailed measurements, are those of the author.*

Features.—(1.) While the general course of the West Rock Range is north-and-south, the western foot of the blunt southern extremity bends round to an eastward course, and ends with north 30° east. The summit of the ridge also curves, in its last 500 yards, around to S. 70° E. or nearly to east-by-west. Its height in this part is 399 to 405 feet above high tide, the geodetic station at the extremity being 399 feet. The eastern foot of the ridge has no corresponding bend.

(2.) The trap of the Rock is a continued mass instead of being divided into several masses through a multiplication of outlets. But it has a large bay of sandstone, of triangular outline, in its southeastern portion, which from its form is called the Triangle. (3.) South of the Triangle there is a prolonged hook-like point making the southeast termination of the trap.

(4.) North of the Triangle commences the trap of the west slope of the mountain. For a distance of 500 feet near the foot, increasing to 800 feet above, the surface of the trap is here elevated sixty to eighty feet or more above the level

* The dotted line on Plate II is the north limit of the map, Plate VI. Heights *C* to *Ca* are plane-table results of Prof. H. A. Newton, from Bache's 399 as base.

farther north. Moreover it is raised into rounded ridges, and some of these ridges have a high inclined wall on the south side. The first of these walls adjoins the Triangle and has a height of seventy-five feet, a slope of about 45° and an even flat surface free from marks of abrasion. Another similar wall farther north is thirty feet high. The smaller troughs are mostly one to three yards deep. The angle of slope in the embossed surface between the 300-foot and 100-foot contour-lines is less than 17°; and in the surface north of it less than 14°. (5.) The long, hook-like point, above referred to, is not a simple ridge of trap, like that from an ordinary fissure, but consists, as seen along its northern side (Plate VI), of a series of rounded ridges which increase in height to the westward, like those of the elevated surface of trap on the other side of the Triangle. Moreover, all these wrinkle-like ridges, concave troughs and oblique walls, have a general parallelism. (6.) The embossed surface north of the Triangle has lost, through glacial abrasion, as a consequence of its elevation above the general level, all of the sandstone once covering it, even to the foot of the mountain, excepting small portions in two of the troughs. Farther north the sandstone remains in some places nearly to the 300-foot contour-line. (7.) The trap of the embossed area that was thus uncovered suffered little from the abrasion; for the rock of the surface has the fineness of grain and other characteristics of the contact rock. This is true also of the trap of the southeast point. Moreover, in many places on this point below 300 feet, the trap contains imbedded fragments of the sandstone which fell into it while it was still liquid. The trap of other parts of West Rock ridge rarely shows evidence of abrasion below a level of 300 feet. On the contrary, above this level it has lost by abrasion the fine-grained, brittle crust-portion, and presents at surface the coarseness of crystalline texture that belongs to the interior of the mass.

(8.) Another very important feature of West Rock is its affording a long east-and-west section through the breadth of a great trap range, exhibiting the contact-plane for several hundred feet of the outflowing trap and the underlying sandstone, as described and figured beyond.

The map, Plate VI, has the walls, troughs, and ridges of the surface shaded, to bring out better these features of the original surface of the trap. The southern front of the Rock has been made by degradation and hence has no shading. The southeastern point owes its straight outline on the south side to the quarrymen and the joints in the trap. The map shows what remained of the point in 1880. There is much less now.

The Supply-fissure.—The inclination and width of the fissures supplying the liquid trap for the West Rock range are

undetermined. Exposures that will afford the facts are most likely to be found along the eastern base of the ridge. At one place where the surface of trap had been uncovered but not abraded, which was seemingly favorable for a safe conclusion, the slope was 25° to 30°, and suggested the angle of 30° for the inclination. But the trap at the place may have been part of the *outflow*, and not that of a dike. Observations along the eastern slope of the range farther north may obtain decisive facts.

The Outflow.—The slopes of the higher parts of the West Rock ridge, the pitch of the columns of the western front, and the resemblance in features of West Rock to East Rock, lead to a like conclusion for the two, that the outflow was laccolithic; in other words, that the liquid rock forced its way between layers of sandstone, and made the chamber it occupied. The present thickness of the mass is nearly 250 feet. The overlying sandstone is to a large extent the weak, chip-making rock of dark red and purplish color already described. It is remarkable that a rock of so feeble coherence could have been lifted in the way mentioned.

The questions suggested by East Rock here come up again: Whether the feeble slope of the surface from the west edge of the summit eastward to the 300-foot contour-line, and the small thickness of the trap, are due to abrasion, or whether the present conditions are nearly those of the original outflow. As the length of the outflow is nearly 500 yards, the mass, if forced up between layers dipping 25° eastward, would have had a much larger amount to lose by abrasion than in the case of East Rock.* Speculation is here set aside by the actual east-and-west section of the Rock which is presented along its southern front, and is shown in part on Plate VII, from a photograph.† It exhibits the trap resting, to the eastward, on

* The thickness does not admit of calculation, because the only datum besides the dip of the sandstone, is the height of the bottom of the trap over the sandstone on the west front (about 200 feet); the height of the outflow where it left the fissure is not ascertainable.

† The fine photograph was taken by M. W. Filley, of the firm of Bundy & Filley, of New Haven. The sandstone has here been exposed to view by the removal of the debris for macadamizing. The irregular line in the plate a third of an inch above the sandstone was the limit of the talus or debris slope; and the line below the sandstone is the profile of the quarry wagon road. Along the part of the section represented, the height of this road is ninety to one hundred feet. If the debris were wholly removed to the bottom of the slope, the height of the sandstone exposed to view would be, where greatest, over 150 feet.

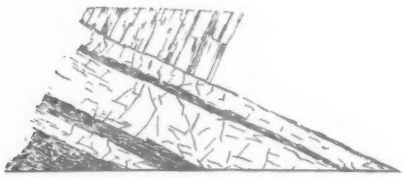
The photograph does great injustice to the view in the diminution of the vertical as compared with the horizontal scale, and also in flattening the angle of dip in the sandstone. 200 feet measured on the quarry road reaches from the eastern point of the sandstone section westward to within twenty-five feet of the line of the deep notch in the columnar front of the Rock (the place where the first section of sandstone ends); but this length applied vertically to the front above the road would make it only 180 feet in height, when in fact this height where greatest is over 300 feet. This error arises partly from the fact that the view was taken from the terrace opposite, which is only sixty feet high, but more from the error in an ordinary lens.

a tilted layer of the sandstone, the dip of which eastward is 25°. We are left to conjecture as regards the eastward and downward continuation of this layer to the supply-fissure (which the further removal of debris might perhaps uncover). But we know that the trap continues up this sloping layer for seventy-five yards from the commencement of the outcrop. It conforms to the theoretical view of an outflow as presented in fig. 10, on page 94.

But on reaching the end of the seventy-five yards, there is a change. The trap beyond rests on the edges of the layers in a series of ledges of the sandstone. Moreover there is but little rise westward along the floor; for a line drawn along the top of the ledges would be almost horizontal, and have therefore near parallelism to the surface of the trap at the summit west of the geodetic station.

The following figure represents the eastern extremity of the sandstone for a height of fourteen feet, together with the

13.



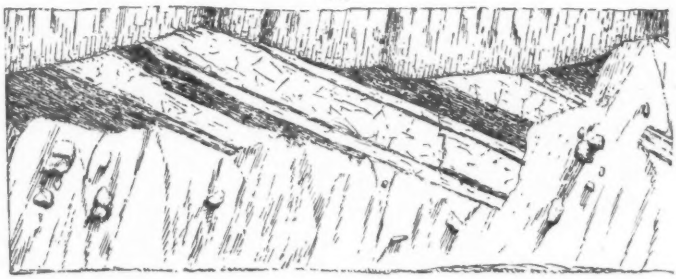
base of the overlying trap. The rock is partly a hard-baked granitic sandstone, and partly the feeble shaly chip-making purplish-red sand-rock. The trap columns above the sandstone have in the lower part an inclination of 20°, approaching thus verticality to the surface of the sandstone; but, higher up the bluff front, there is a gradual change to 5°, which is the prevailing inclination.* The upper layer of the sandstone where uncovered shows a surface without breaks or much unevenness.

A section of the sandstone, with the trap above, for the next seventy-five yards is represented in the following figure. The fact that the trap when melted flowed over the upturned edges is manifest. The chip-making rock constitutes much of the mass, and at its contact with the trap it is scarcely changed in color or texture. The trap is far more finely columnar than that to the east over the single sandstone layer, and probably because moisture reached the trap freely from between the upturned layers. Other sections farther west are of similar

* The angles of inclination here recorded are those presented to an observer in the front view of the rock here described.

character, excepting that the apparent dip is less. They may be followed westward along the quarryman's road for 400 yards, when they begin to pass into the normal sections of the western front, that is, sections in which the lines of bedding are horizontal because they are in the line of strike of the sandstone.

14.



The question here arises: Did the flowing trap, owing to its movement and weight, wear off the layers of sandstone and so make the succession of ledges on which it rests; or did it escape from its confining cover of sandstone into the open air and cover in its flow the exposed ledges of the region. The former is probably the correct view. Had the flow become subaerial there would have been at once a decline westward in the level of its upper surface; for the level would have fallen as soon as the resistance from confinement ceased. There is no evidence of such a decline. From points on the summit close to the western precipice the surface for the first 300 yards has generally a slope eastward of 1 to 4, or 1 to 5, corresponding to a pitch of 14° to 11°. The decline is eastward; not westward. Such a rise westward, even if only 5°, would be an impossibility except in a covered passage-way, that is, in the present case, one having a cover of the sandstone. Other evidence bearing in the same direction is afforded by the position of the columns along the western front, which pitch westward 15° to 20°.

The summit slope eastward of 14° to 11° is less than the dip of the sandstone, and favors the conclusion that the underlying sandstone was in many places torn up by the heavily moving liquid trap, while left in place elsewhere. The floor so made consisted of alternations of wide strips that had the regular dip of the sandstone, with others abraded down to nearly flat and ledgy surfaces; and the former prevailed sufficiently to determine the direction of the contractional

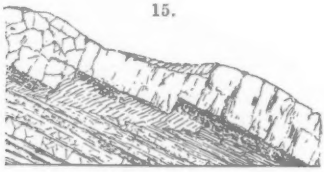
fracture-planes or the columnar structure. A reduction so nearly to horizontality as that shown in the south front of West Rock along with parallelism in the profile of the summit may not be common.

West Rock teaches that the section of East Rock in fig. 11, p. 95, may be no exaggeration. Yet it is more probable that the original condition was intermediate between this position and that indicated in this diagram.

Sections similar to that in the south face of West Rock may be looked for, with some probability of success, among many of the trap-ranges of the Connecticut Valley wherever they terminate in transverse sections. All that is necessary to ascertain the truth is to remove the talus of trap debris.

Three miles east of New Haven (in East Haven) a section was opened in cutting for a carriage-road through the second trap ridge west of Saltonstall Lake; it is but a few rods west of the railroad station. The facts are in all respects similar to those of West Rock, as shown in the annexed figure. The

15.



trap covers a series of ledges of upturned sandstone, and shows no traces of displacement subsequent to its cooling. The sandstone is intersected by extensive nearly vertical fractures, whose surfaces, owing to friction, are scratched and polished; and the larger planes extend up through the sandstone without any appearance of corresponding displacement in the trap. Moreover these polished slickensided surfaces have the white porcellanous coating common in the region; probably made by the grinding of the feldspar of the sandstone in the mutual friction of the walls.*

* At all the East Haven quarries, and in the ledges elsewhere exposed to view, these evidences of displacement and of much friction attending it abound. Fragments as large as the hand, slickensided on both surfaces and over planes of cross-fracture, are common; and so are walls of various inclinations hundreds of square yards in area. The sloping upper surfaces of the sandstone layers laid bare in the quarrying are sometimes polished and scratched in the direction of the dip for many square rods. There is abundant evidence of a vast amount of movement, though movement in a small way, during the progress of the upturning in which the sandstone received its universal eastward dip.

The section represented in fig. 15 has lost much of its original distinctness by the sliding down of debris from above.

The trap of this ridge, at a higher level above the sandstone, is more or less chloritic and in many places amygdaloidal. Part of the amygdules are slender cylinders, two to three inches long and like pipe-stems in size, occurring often in groups—the result probably of the sudden vaporization of particles of liquid carbonic acid.

In the railroad gap through the Saltonstall Ridge, the first west of Saltonstall Lake ("Pond Ridge" of Percival), the sandstone appears to lie in a similar manner unconformably beneath the western extension of the trap. But the section is now too much covered by debris for a satisfactory observation. Two miles east of the Saltonstall ridge in Branford, as described by Mr. E. O. Hovey,* the trap of a short range, the easternmost in this part of the sandstone region and near the gneiss boundary, overlies the *upturned* edges of the sandstone, and there is between the two rocks a layer of sandstone conglomerate containing nodules of trap, which he attributed to the rubbing action of the flowing trap on the sandstone.

These facts, ranging in this part of the Connecticut Valley over the whole breadth of the Jura-Trias formation, from the west side of the New Haven region where the trap is of the compact non-vesicular kind to the dikes of vesicular trap toward and near the eastern gneissic border, have great importance in their bearing on the subject of the other Jura-Trias ridges. The more eastern are placed by Professor Davis among the ridges made of horizontal subaerial flows, ejected before the upturning of the sandstone; and the more western he has regarded as horizontally ejected and subsequently upturned, although admitted to be interstitial intrusions. Neither of these conclusions are sustained by the facts which have been presented.

The facts prove further that the era of disturbance or of the upturning of the sandstone was not due in any way to the ejection or heat of the igneous rock. The latter event, although so extensive, was simply incident to the disturbance; the upturning preceded the eruptions.

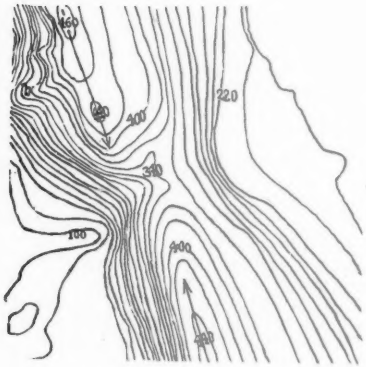
Effects of Obstructions to the outflow.—Although the trap of West Rock—that is of the southern part of the West Rock ridge—is not divided into several areas, other effects of obstructions may be looked for, since the hanging wall of a large inclined fissure is sure to have its downfalls. The gaps or notches in the ridge indicate incipient division, and may be among the effects from such a cause. They may have been produced also by local narrowings of the fissure through horizontal or oblique movement of its walls, or in other ways; and it is a question whether the results of these two modes of origin can be dis-

* This Journal, vol. xxxviii, p. 361, 1889.

tinguished. The deeper and more abrupt notches we should be disposed to refer to the former cause.

As the Bache map of West Rock ridge indicates by its contour lines, within a mile and a quarter of the south end of West Rock, there are three gaps. Two are included on Plate II. At the first, the height of the ridge falls off sixty feet in the course of 500 yards. The second, situated 300 yards farther north, and called the "Judges' Notch" because near the "Judges' Cave," is similar to the first in depth, but narrows more down the western front. Half a mile farther north is the third, called the "Wintergreen Notch." It is one of the larger gaps in the ridge. Along the summit, both from the north and the south, there is a descent of 100 feet, from a height of 440 feet to 340. Figure 16, from the Bache map, exhibits the facts.* The decline is gradual on the south side, but very rapid northward; in the latter direction the level of 460 feet is reached at the same distance from the center of the gap as 440 on the south. This third gap is probably one of those caused by obstructions to the outflow, whatever the fact with the others. The stream, in consequence of the obstruction, reached a height at the gap of but 340 feet; but just beyond, the lavas that had been held back, made the abrupt rise in the ridge to 440 and 460 feet. The correctness of this explanation appears to be sustained also by the abruptness of the rise in the slopes east of the gap, as the contour lines in the figure show, and the great breadth of the nearly horizontal area farther east. It will be observed also that the summit of the ridge north of the gap is farther to the west than that on the south. (Arrows are inserted to make this distinct.) It is so because any given amount of trap depends for its height on the distance it flowed westward up the inclined sandstone layers. It may be observed that not only the height,

16.



Wintergreen Notch.

* The west side of the ridge in this part, as elsewhere, is the precipitous side, bold columnar above. Its upper 200 to 225 feet usually consist of trap, and the part below of sandstone; but the junction-plane at the Notch is concealed by trap debris, so that its actual height is not determinable.

460, but also 440 on the north side is to the west of 440 of the south side; but the height of 440 to the north is probably produced with a less thickness of trap. This notch is 300 yards south of the Buttress dike described on a former page; the position of this dike is shown on the above figure at *b*.

This example will suffice for illustration. Other gaps in the ridge occur farther north, but they are outside of the region here under consideration.

Obstructions to the outflow of lava while it was making its way between the layers of sandstone are also possible through any cause that would prevent the lifting of any portion of the overlying rock. The area of the Triangle has been described as an area of sandstone within the proper limits of the trap range. This sandstone was not lifted like the rest of the overlying stratum. Instead of this, it remained in place for the most part, and hence, forced the liquid rock to pass to one side of it. The lava, mainly took the north side; and so the trap of that side had its surface raised in level above the rock north and became the elevated embossed area already described. The great sloping trap wall making the north side of the Triangle is the wall of an oblique fissure in the sandstone formation. Along this fissure—45° in inclination,—the sandstone of the south side, or that of the Triangle, lay unmoved or nearly so, while that of the north side was shoved up as the lavas came in below. Other walls, and the small ridges both north and south of the Triangle, are evidences of similar fractures, in parallel directions, with analogous results. The unlifted sandstone was in some way put under a strain that produced the parallel fracturing and movements.

The origin of the southern or western walls of West Rock is sufficiently explained in the remarks on this subject respecting East Rock (page 94).

The southern front of West Rock has a columnar aspect. But in reality no columns stand out with the boldness they have in East Rock. The surface is mostly made up of the cleavage surface or joints that are in its plane; and where there has been quarrying, these joints have great width as well as height.

3. Relation of the east-and-west and north-and-south fissures, and the origin of these courses.

These two courses of fissures are so locked together in the New Haven region that they evidently are results of one system of movements. They occur together in Pine Rock; and West Rock has the general trend of the Pine Rock ridge represented in the embossed area and the southeast point.

Mill Rock ends to the eastward in a south-southwest fissure, transverse to its main course which is apparently parallel to the adjoining part of the East Rock trap. East Rock commences with a nearly north-and-south course, but bends around to east-southeast. Mill Rock and Pine Rock are not necessarily synchronous in eruption with East Rock or West Rock, but they belong to one epoch of disturbance.

The origin of these courses is not fully ascertained. I have long explained the north-by-east trend of West Rock, and of the other ridges of like direction to the north, on the general principle that the mountain-making forces of Eastern America operated over any part of the area, as a general thing in the same direction from Archæan time onward, examples occurring in the Taconic and Jura-Trias elevations of the western half of New England. In accordance with this view the strike of the Jura-Trias should be that of the underlying crystalline rocks. It does not follow that a like dip prevails in the schists beneath. It is true however that the predominant dip in them, and in the Jura-Trias fissures and bedding, is eastward. This last fact seems to favor the suggestion of Professor Davis that the foliation of the underlying schists has determined the courses of fissures in the Jura-Trias area. This suggestion would have support in the fact, were it not that in New Jersey, where the same is true as to the dip of the underlying schists, the Jura-Trias fissures and bedding dip westward.

In the New Haven region, the idea of an accordance between direction of foliation in the schists and of fissures in the Jura-Trias finds no support. The West Rock ridge crosses the line of strike of the metamorphic schists two miles west of it at an angle of 20°. East Rock has an east-of-north course only in its northern extremity, and curves around through nearly half a circle. Pine Rock and Mill Rock cut across any probable course of foliation in underlying schists and do it on lines that differ 50° in trend.

The origin of the east-and-west courses, which commence in the extremity of West Rock and continue to Whitney Peak, four miles, may have its explanation suggested by the remark on page 80. Or, it may be a consequence of the movement attending the production of the north-and-south fissures, and local to the New Haven region. The subject at present is one of conjectures.

On account of the interest of the dynamical question here brought into view, I introduce another illustration of the facts from a transverse ridge only six miles north of Whitney Peak and Mill Rock. It is called Mt. Carmel. The ridge is only one and a half miles long. It is higher than those already

considered, the most elevated point being 736 feet above high tide.* But height means here, not larger accumulation of igneous rock or trap, but, simply, greater emergence above the sea-level; for this increase northward of height runs parallel with a like increase in the height of the metamorphic ridges just west; and it is continued, at a diminished rate, into Massachusetts.

Mt. Carmel has resemblances to Pine Rock. Its mean course is E. N. E.; and a north-and-south trend exists in its western part. But the north-and-south portion in Mt. Carmel is a large feature in the ridge and has direct continuity with the east-northeast portion.

The ridge is divided by a very deep and open gorge, into an eastern and a western section. The gorge is often called the "Neck," and the high summit adjoining it on the west, the "Head" of the "Sleeping Giant"—a name suggested by the form of the ridge as it appears lying on the northern horizon. Both have northern and southern slopes of sandstone, the southern going about half way to the top above its base, and the northern reaching a greater height.

The western section, while high and massive at its eastern extremity, falls off rapidly to the westward, and in half a mile is reduced to a narrow trap ridge not exceeding 100 feet in height above the adjoining country. Through this part within 300 yards, pass Mill River, a north-and-south carriage road (N. 20° W.) without change of grade, and, a few rods farther west a railroad. Along the railroad, and between the carriage road and the river, the course of the trap changes from about north-and-south to N. 10° E.; and as it crosses the river to N. 20° E. Thence it continues on to the summit, widening and increasing rapidly in height and curving still farther eastward.

At the section in the railroad cut, the trap is seen resting on its south wall of sandstone, the wall dipping about 45°—apparently indicating that the dike has this pitch. Between the carriage-road and Mill River, the north side of the trap has in many places a westward dip of the same angle, confirming the conclusion from the railroad section as to the large dip of the fissure. It is thus proved that the western section is a continuous mass of trap of gradually changing course and magnitude; and that it is strictly "transverse" in direction only along its eastern end. It is a dike to the westward and probably so throughout.

The eastern section is made one continuous mass of trap by Percival, and one also with the western portion. It is divided

* According to the leveling of two parties under Mr. Bache.

from east to west, as he states, by a valley, and in the valley there is a spring giving out a streamlet which flows northward. There are gaps in both the southern and northern sides, dividing them into a series of elevations. These elevations are indicated on Percival's map, so as to look as if he regarded them as separate dikes; but this is contrary to the description in his Report. I have looked for sandstone in two of the gaps of the south side, east of the "neck," and have found evidence in each that the trap is continuous, and descends in these gaps nearly half way to the base of the mountain. In the east-and-west valley the spring and streamlet are probable evidence that there is sandstone beneath; and on this ground, it may be that there are, in this eastern part of Mt. Carmel, two parallel east-and-west dikes.

Mt. Carmel appears to be a combination of dikes, without the "buried volcanoes" supposed to exist there by Professor Davis. In the view from the west side of Mill River there are in sight nearly 600 feet in height of massive trap, having no subdivision into sheets or layers, and nothing to suggest the idea of lava-streams in the depths below.

The union in this small ridge of approximately north-and-south and east-and-west courses is further proof of their mutual dependence in the system of movements attending the Jura-Trias mountain-making of the Connecticut Valley. But its origin remains unexplained.

Concluding Remarks.—A review of the principal conclusions in this paper is given in its introductory remarks (page 82), and a recapitulation here is therefore unnecessary.

The reader may have been led to the idea that the author would make the West Rock Ridge typical for other ridges of like features in the Connecticut Valley region, in disagreement with the conclusion of Professor Davis who holds that in the case of most of these ridges, if not of all, the trap was poured out in one, two or more horizontal sheets, separated, and overlaid horizontally, by beds of sandstone, and that the whole was afterward faulted and tilted so as to make the ridges. The author acknowledges that he is inclined to make the conclusions he has reached general. He, however, admits that he has not made the structure of the other ridges of the valley a special study. He believes his observations sufficient, however, to authorize the statement that a more intimate knowledge of the facts is required before any adverse views can be regarded as established.

PLATE II

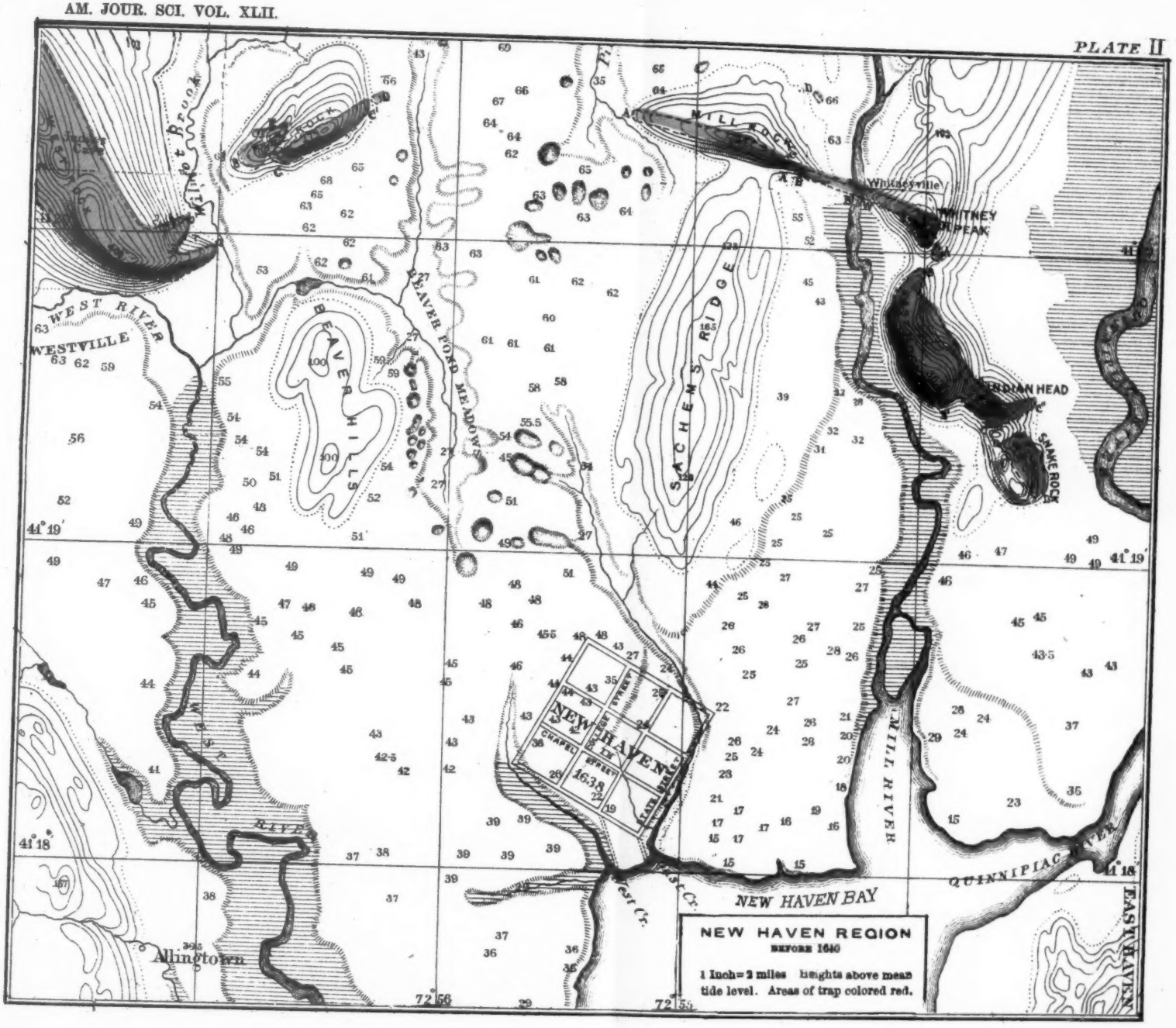
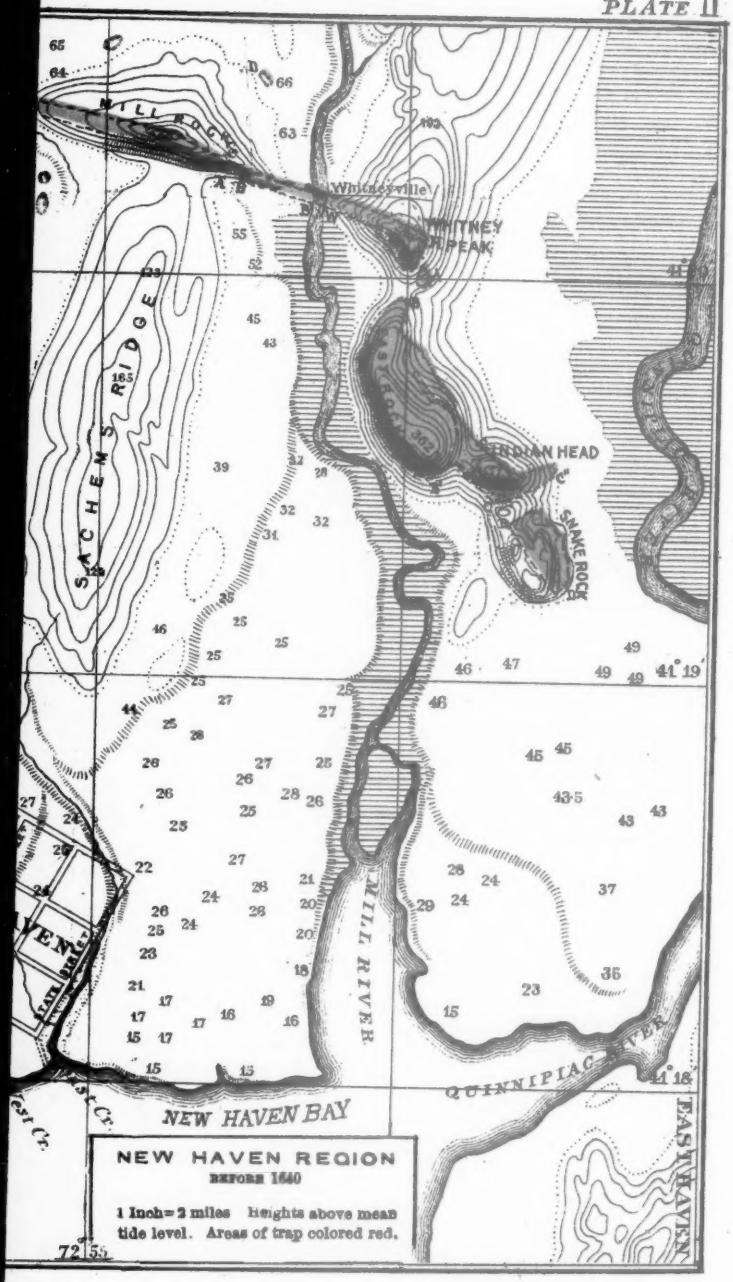
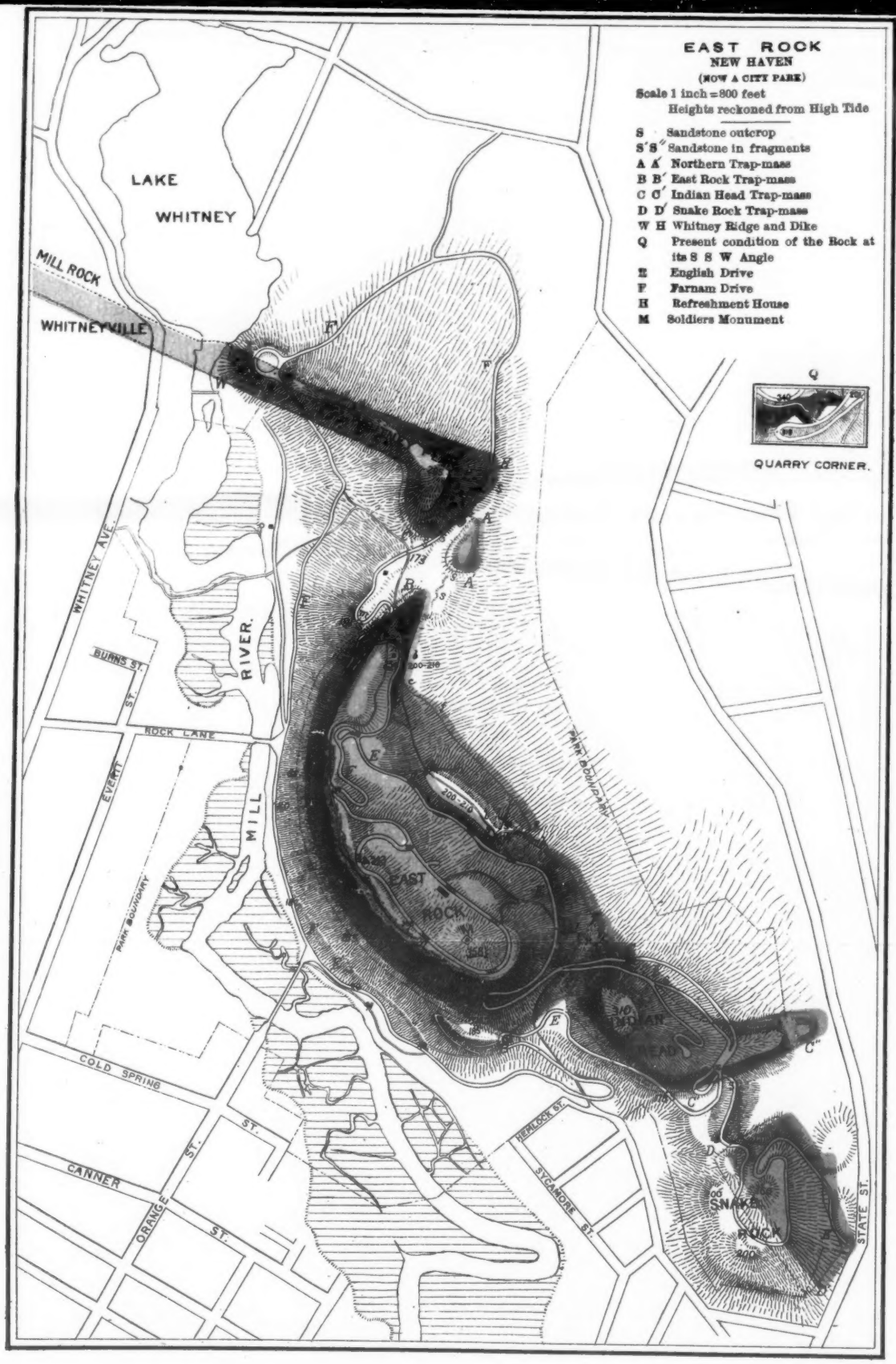
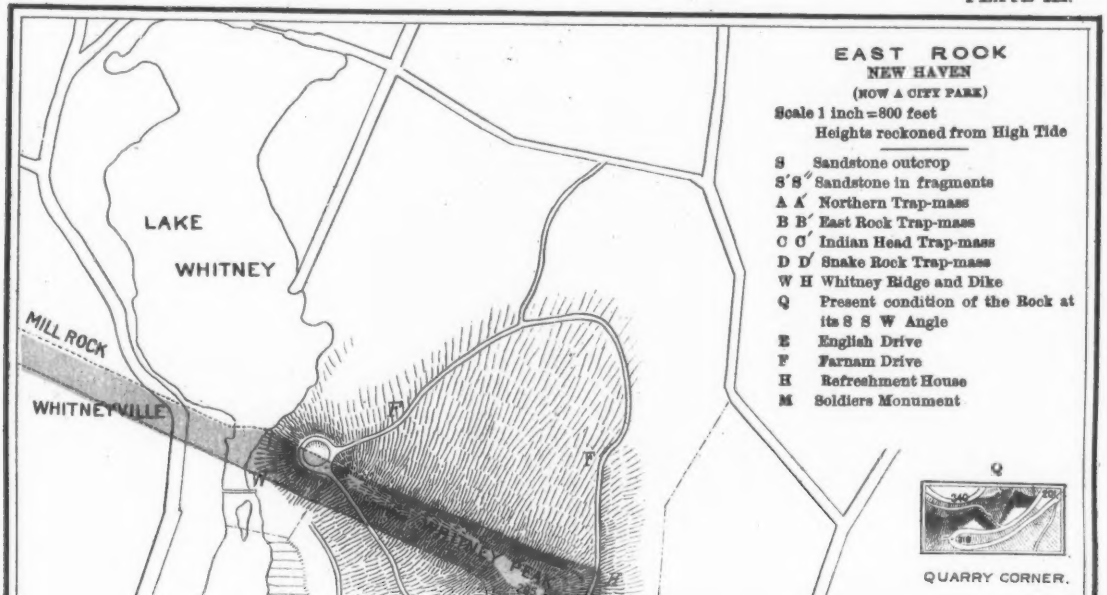

WEST RIVER
WESTVILLE
BEAVER HILLS
BEAVER POND MEADOW
SACHEM'S RIDGE
MILL ROCK
Whitneyville
WHITNEY PEAK
EDGEHILL
EDGEHILL HEAD
SNAKE ROCK
NEW HAVEN
1638
CHAPEL
YALE
COLLEGE
EXCHANGE
GREEN
MILL RIVER
QUINNIPIAC RIVER
NEW HAVEN BAY
EAST HAVEN
Allingtown
41° 19'
41° 18'
72° 56
72° 55
NEW HAVEN REGION
BEFORE 1640
1 Inch = 2 miles Heights above mean tide level. Areas of trap colored red.

PLATE II


MILL ROCK
Whitneyville
WHITNEY PEAK
SACHEMS RIDGE
INDIAN HEAD
SNAKE ROCK
MILL RIVER
NEW HAVEN BAY
QUINNIPIAC RIVER
EAST HAVEN
NEW HAVEN REGION
BEFORE 1640
1 Inch = 2 miles Heights above mean tide level. Areas of trap colored red.


EAST ROCK
NEW HAVEN
(NOW A CITY PARK)
Scale 1 inch = 800 feet
Heights reckoned from High Tide
S Sandstone outcrop
S′S″ Sandstone in fragments
A A′ Northern Trap-mass
B B′ East Rock Trap-mass
C C′ Indian Head Trap-mass
D D′ Snake Rock Trap-mass
W H Whitney Ridge and Dike
Q Present condition of the Rock at its S S W Angle
E English Drive
F Farnam Drive
H Refreshment House
M Soldiers Monument
Q
QUARRY CORNER.
LAKE WHITNEY
MILL ROCK
WHITNEYVILLE
WHITNEY AVE.
BURNS ST.
ROCK LANE
EVERIT ST.
MILL RIVER.
PARK BOUNDARY
EAST ROCK
INDIAN HEAD
SNAKE ROCK
COLD SPRING ST.
CANNER ST.
ORANGE ST.
HEMLOCK ST.
SYCAMORE ST.
STATE ST.

WHITNEY AVE.
BURNS ST.
ROCK LANE
EVERIT ST.
RIVER.
MILL
EAST ROCK
PARK BOUNDARY
200-210
200-210
QUARRY CORNER.


EAST ROCK
NEW HAVEN
(NOW A CITY PARK)
Scale 1 inch = 800 feet
Heights reckoned from High Tide
S Sandstone outcrop
S′S″ Sandstone in fragments
A A′ Northern Trap-mass
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W H Whitney Ridge and Dike
Q Present condition of the Rock at its S S W Angle
E English Drive
F Farnam Drive
H Refreshment House
M Soldiers Monument
LAKE
WHITNEY
MILL ROCK
WHITNEYVILLE
Q
340
250
QUARRY CORNER.

View of East Rock from the southwest, near Orange Street Bridge.

(From a photograph.)

Profile view of columns, East Rock, near the house on the brow of the Rock in Plate IV.
(From a photograph.)

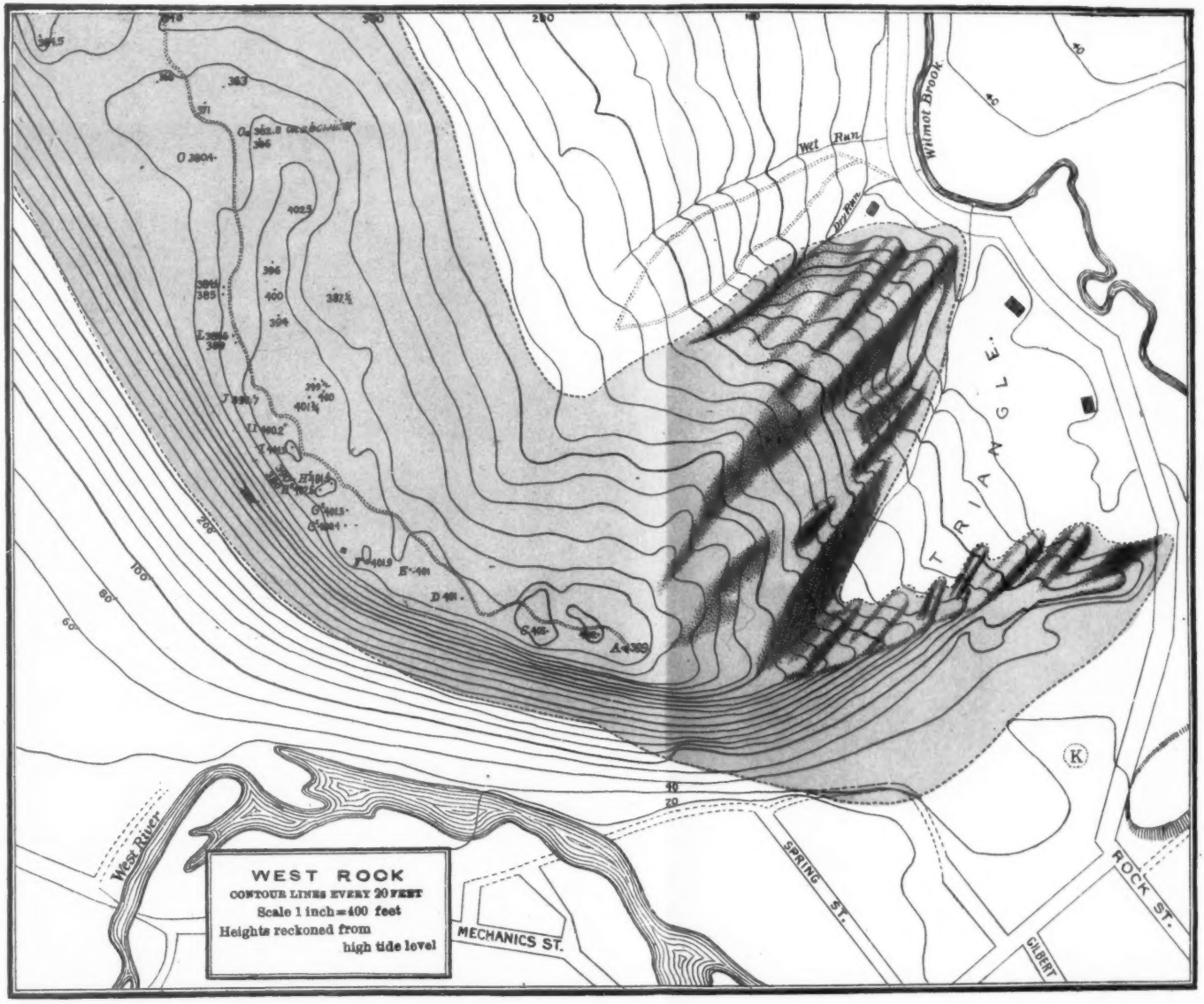
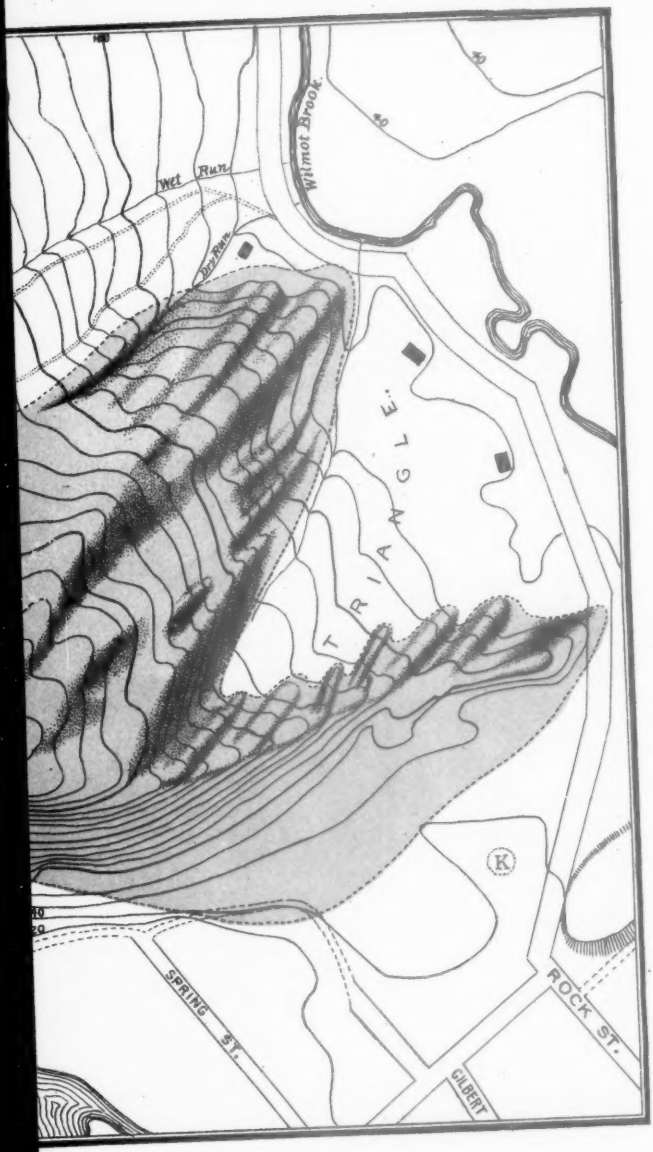

WEST ROOK
CONTOUR LINES EVERY 20 FEET
Scale 1 inch = 400 feet
Heights reckoned from
high tide level
West River
MECHANICS ST.
SPRING ST.
ROCK ST.
GILBERT
Wilmot Brook
Wet Run
Dry Run
TRIANGLE
K

PLATE VI.



View of the south front of West Rock, showing the trap of the outflow overlying upturned sandstone for a distance of 550 feet. (From a photograph.)

ART. XI.—*Notes on a Reconnaissance of the Ouachita Mountain System in Indian Territory;* by ROB'T T. HILL.*

Synopsis.—General topographic features of Indian Territory including Oklahoma. The northern, middle and southern belts. The middle or mountainous belt. 1. The Eastern or Arkansas-Choctaw Division. 2. The Central or Chickasaw Division. 2*a*. The Wapenucka Sub-division. 2*b*. The Tishomingo Granite. 2*c*. The Arbuckle Mountains and Washita Water Gap. 3. The Wichita Division. Partial record of history recorded in the Ouachita System.

LITTLE has been written concerning the geography and geology of Indian Territory, and the writer presents this preliminary paper in hope that it will direct to that interesting region more careful and detailed study.

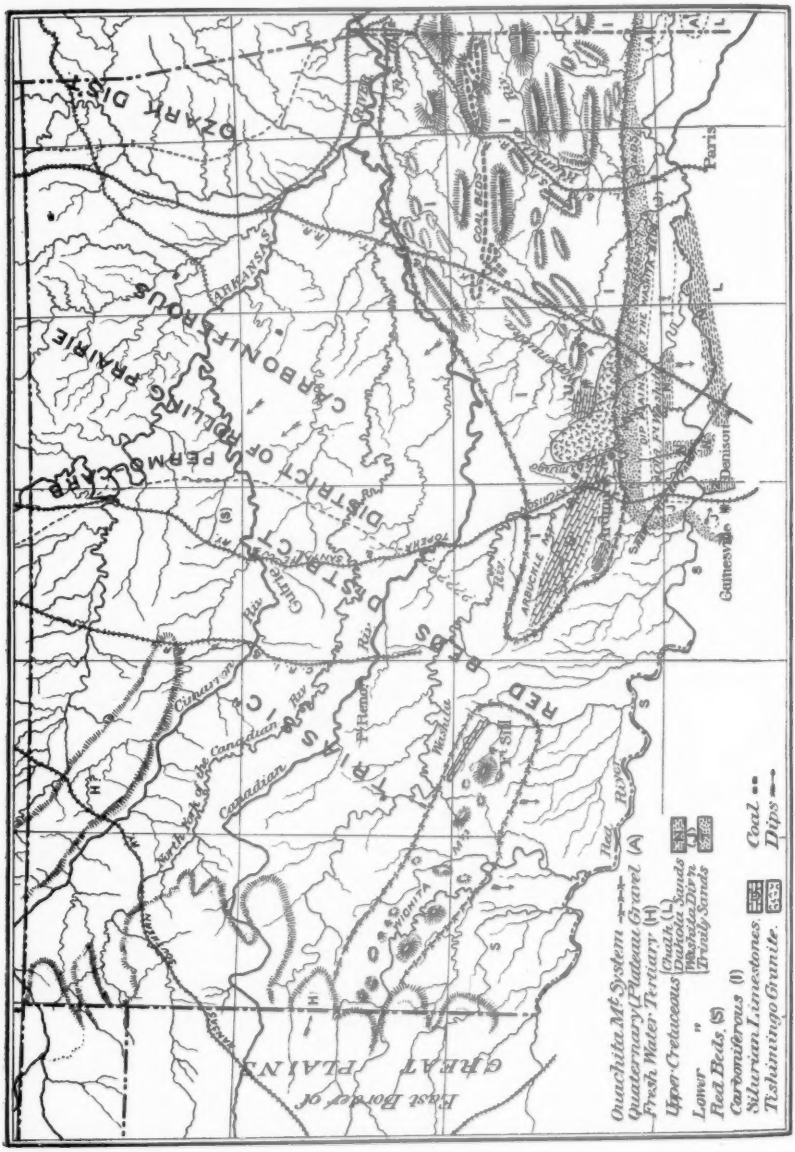
Topographically Indian Territory, especially its southern half, presents a great diversity of mountain, plain, forest and stream. Within this area is found the extension of nearly every topographic unit from the Missouri-Kansas region on the north to the Texas on the south, from the Great Plains of the west to the forests of Arkansas on the east; there are also many unique characteristic features of the region itself.

The territory may be provisionally divided into three parallel east and west belts, each containing a marked diversity of geologic structure and corresponding topographic expression.

The northern or Cherokee-Oklahoma belt includes the country north of the Canadian; the greater part is prairie with spots of timber decreasing in density toward the west. This belt may be sub-divided into three districts; the eastern or Cherokee, the middle or Oklahoma, the western or Arrapahoe. The Cherokee division, with the exception of a small area of Ozark hills in the northeast corner, is mostly composed of Carboniferous rocks with an undulating topography similar to that of southeast Kansas. The Oklahoma section is a typical red bed region in its western half, with undulating prairies and soft disintegrating structure. The Arrapahoe division is the ragged eastern border of the great plains country, with its characteristic fresh water deposits of sands and grits occupying the flat divides, as originally described in the adjacent west Kansas region by Dr. J. S. Newberry and more recently by Professor Robt. Hay.† These plains are the newest or culminating formation in western Texas, Kansas and Indian Territory; they are now slowly receding westward because of the head water erosion of the streams that indent this eastern border,

* To Mr. James S. Stone, of Newton, Massachusetts, the writer is greatly indebted for his faithful assistance in conducting this investigation. Also to Mr. W. L. Davidson, a student of the University of Texas.

† See Bulletin 57, U. S. Geological Survey.


Ouachita Mt. System
Quaternary & Plateau Gravel (A)
Fresh Water Tertiary (H)
Upper Cretaceous (Chalk, (L)
Dakota Sands
Washita Div'n
Trinity Sands
Lower " (J)
Red Beds, (S)
Carboniferous (I)
Silurian Limestones
Tishimingo Granite
Coal
Dips
GREAT PLAINS
East Border of
CHEROKEE PRAIRIE
CARBONIFEROUS
DISTRICT OF PUBLIC
OZARK DIS.
RED BEDS
DISTRICT
CANADIAN
Paris
Denison
Gainesville
Red River
Canadian
North Fork of the Canadian
Cimarron
Arbuckle Mts.
Wichita Mts.
Fort Sill

and in this manner the underlying structure and topography are revealed. The northern belt of Indian Territory distinctly belongs to the Kansas division of the United States and the writer leaves its further description to St. John, Cragin, Hay and Jenney, investigators who possess more facts concerning its geology.

The middle or mountainous belt lies south of the Cañadian-Arkansas River. A mountain system traverses it from east to west and marks the great barrier between the upper Mississippi Valley and the Texas-Arkansas regions of the United States.* To a description of these mountains this paper is mostly devoted.

The third and southern belt, the description of which must be left to a future paper, includes the region between the mountainous belt and Red River. It is the northern termination of the Texas region of the United States. It includes many topographic and geologic features which are the result of neozoic sedimentation against the southern border of the mountains.

The Mountain Region of Central Indian Territory.—With the exception of the Ozark hills in the extreme northeastern corner, the mountains of Indian Territory are the direct westward continuation of the Ouachita system of mountains which has been described† as the mountainous area between Hot Springs Arkansas and the Staked Plains of Texas, including the various points known as the Poteau, Seven Devils, San Bois, Shawnees, Jack's Fork, Black Fork, Winding Stair, Sugar Loaf,‡ Cavenal, Stringtown Hills, Limestone Ridge, Potato Hills, Arbuckles, Wichitas, Navajoes and other mountains. These mountains are south of the Arkansas-Canadian drainage and must not be confused with the Ozarks of southwestern Missouri. Dr. J. C. Branner's coming reports will doubtless give us needed light on this relation.

The mountain belt has three distinct sub-divisions: (1) an eastern or Arkansas, (2) a central or Chickasaw, (3*a*) western or Wichita. Its areal extent may be compared to an arch whose apex is southward, as marked by the course of the Canadian, Arkansas and Red River drainage; its eastern member in Arkansas and the Choctaw nation is a forest area of vertically folded Carboniferous shales and sandstones resembling the Appalachian country; the western member in the Chickasaw and Comanche nations, is a mostly treeless region and consists of low folds of hard white and blue Silurian lime-

* See this Journal, April, 1889.

† Arkansas Geological Survey, 1888, vol. ii. The geology of Southwestern Arkansas, by Robt. T. Hill.

‡ Near Fort Smith, not the Cretaceous butte of the same name east of Caddo.

stones and eruptives; the keystone or central Chickasaw region, consists of an area of granite and Silurian limestones.

1. *The Eastern or Arkansas-Choctaw Division.*—The northern two-thirds of the Choctaw nation and the northeastern Chickasaw country are a direct continuation of the mountains and geologic features of west-central Arkansas. This region consists of numerous timber-covered ridges varying in altitude from 2700 feet along the Arkansas line to 1200 along the Missouri, Kansas and Texas railroad. The ridges are usually elongated, timbered, devoid of sharp peaks and owe their present form to the unequal erosion of the exaggerated structural folds. The general trend of these mountains, corresponding with the strike of the folds, is south of westward, but often, as seen near Stringtown and along the Kiamitia River, it is nearer north and south. The ridges consist of sandstones, clays and shales apparently of the Carboniferous period, but further investigation may reveal older rocks. The rocks occur in numerous parallel, overlapping folds, which are nearly vertical in the southern and central portion of their extent, but become horizontal along their northern outline.

1.

Section north and south across Red Bird Mts., showing relation of Mountain folds to Cretaceous Prairies.

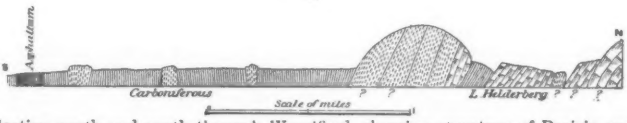
The Saint Louis and San Francisco railroad, from Fort Smith, Arkansas, to Paris, Texas, passes through the heart of the region, and the type structure, as seen along this route, consists of vertical eastward folds dislocated by another and later movement, as seen south of Tushka Homa, the Choctaw capital. This road follows for miles the water gap of the Kiamitia River, which apparently flows in an anticlinal valley. A hundred miles west of this railway, the Missouri, Kansas and Texas road affords another parallel north and south section of the mountain system, but owing to the gradual cessation of timber and decreasing altitude entirely different scenic effects are revealed. The latter road follows the valley prairies between the mountain ridges, which here have the contour and altitude which, in Kentucky, would be called knobs. The railroad follows the strike of the structure from Atoka to Limestone Gap. The differences in elevation are the result of unequal weathering of the crumbling shales and the more resisting sandstones and limestones, the former being treeless valleys while the latter persist as mountainous ridges. (Fig. 3.) Timber grows upon the sandstone outcrops while the

prairies occupy the more compact clays of the valley. Even where the vertical outcrops have been eroded to a level plain, the alternations of sandstones and clays can often be traced for miles by the timber which follows the sandstone outcrops in narrow ribbon-like parallel belts. (See fig. 2.)

The northern half of this area contains coal strata whose extent and known occurrence are indicated on the map. An admirable paper upon the structure of these coal beds has been published by Mr. H. M. Chance.* Mr. Arthur Winslow† has equally well defined them in Arkansas. Mr. J. T. Munson of Denison, Texas, has much unpublished information concerning the formation of this region, and to him the writer is indebted for his invaluable assistance and data.

The coal fields, for which the name Fort Smith-McAllister area is most appropriate, are of great commercial importance, for they are the chief source of fuel supply for the Arkansas-Texas region. These extend along the northern border of the mountains and are terminated on the southwest by the Silurian and granite field of the Tishomingo district which are an apparent barrier between this and the Texas-Ardmore coal

2.



Section north and south through Woodford, showing structure of Prairie and Mountain. Continuation of fig. 1.

field, the fuel of which is of an entirely different character and should not be confused with it‡ geographically, structurally, or economically.

Mr. Chance has published a section of the rocks of the eastern division. He estimates at least 8500 feet of coal-bearing strata, but the total thickness of the Carboniferous and Permo-Carboniferous, as seen in the folds near Ardmore, is greater by the addition of the uppermost or Permo-Carboniferous which here has a thickness of several thousand feet.

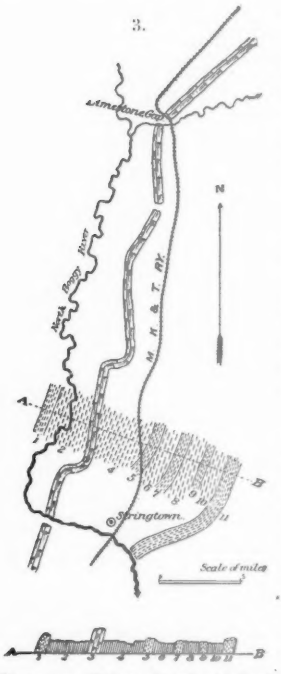
The most marked feature of these mountains is the excessive, compressed and vertical folding which the whole region has undergone, and the displacement of these folds by a lateral dislocation which has squeezed them into S-shaped flexures. So excessive is this folding that every stratum in

* Geology of the Choctaw Coal Fields by H. M. Chance. Transactions American Institute of Mining Engineers, Feb., 1890.

† Arkansas Geological Survey, Report for 1888, vol. iii.

‡ The writer is inclined to believe that the greater excess of ash in the coals of the more horizontal Texas region is due to the calcium carbonate and other impurities deposited in the joints during their long submergence beneath the Cretaceous seas, while the McAllister coals have remained above water.

the mountain region south of the coal fields can be said literally to be standing vertically as shown in the figures. This system of folding is complicated and the writer has not had time for the minute study necessary to interpret it. In general, two great trends or strikes are conspicuous, the first and oldest is about 25° south of west; this is frequently dislocated by an apparently later movement resulting in northeast and southwest trends, all of which are accompanied by overlapping and lack of continuity.* The direction of the folds has a marked effect on the political features of the region, all lines of transportation and public highways practically following the valleys of erosion in the trend of the folds.



Limestone Ridge, showing deflected mountain folds.

The proof of two great dislocations of the Carboniferous strata is found in the mountains north of Atoka and in Limestone ridge where the vertical folds of the first epoch are deflected by S-shaped dislocations into the southeast course.

Of the many illustrations of this folding one of the finest is found in the peculiar limestone ridge which extends from near Lehigh to Limestone Gap and eastward. This is the principal limestone stratum of the Carboniferous system; it occurs at the base of Mr. Chance's section. It consists of about 200 feet of massive blue limestone and dolomite standing vertically. From near Wapenucka via. Lehigh to Limestone Gap, thence eastward to the St. Louis and San Francisco railroad, it forms a sharp ridge rising 100 feet above the adjacent valleys, a plan and cross section of which are given in the accompanying figure (3).

The Missouri, Kansas and Texas railroad, between Stringtown and Limestone Gap, follows the valley east of this ridge; at the latter place a tributary of the Red river has cut through the ridge which, from this point, trends eastward as shown in

* Dr. John C. Branner, on page 30, vol. i. of his report, has previously expressed an opinion that in Arkansas these folds are of overlapping rather than of continuous strike, as stated by Comstock in the same volume.

Mr. Chance's map. Several sigmoid or S-shaped flexures occur along this section, and, also, in the sandstones of the Coal Measures of eastern Indian Territory and across the Territory to the Arkansas line.

The southern border of this old system has been degraded* by the shore lines of the ancient Cretaceous and Tertiary seas which overlapped it and planed it northward for many miles. The vertical edges of the planed off strata are buried beneath the Cretaceous sediments as shown in my former section along the Arkansas-Texas line, resulting in the complete interment of the Carboniferous system southward, throughout the great central denuded region of Texas where the only exposures of Carboniferous rocks are through erosion of the overlying Cretaceous layers. The structure of these mountains is of the Appalachian type, and Mr. Chance says that "topographically and structurally the Choctaw coal fields represent in miniature the features of the anthracite regions of Pennsylvania."

2. *The Central or Chickasaw Division.*—In the northeastern part of the Chickasaw nation the continuity of the Carboniferous rocks is terminated by an extensive area of Silurian limestones, which, in turn, are succeeded southward by underlying granites whose exact relation to the complicated Coal Measures is not determined, but which are exposed by the erosion of the latter and are unconformable beneath them.

2*a*. *The Eastern or Wapenucka* portion of this area is interesting, but little explored. It lies west of Boggy station along Delaware Creek at Bill Jackson's ranch, and near the quaint old Chickasaw academy of Wapenucka. There is a series of low limestone hills—apparently remnants of anticlinal folds—along whose strike flows the Delaware creek. In places these limestones resemble the blue Silurian limestone to be described in our discussion of the Arbuckle Mountains, but they are more horizontal in outcrop. In the collection of Mr. J. T. Munson, of Denison, who first called my attention to this interesting region, are fossils apparently Silurian in age Orthoceras and Brachiopoda, from Bill Jackson's ranch on the Delaware.†

Crinoidal limestones of Carboniferous age are the prevalent rocks and were collected near the academy at the southern border of the district, and the sandstones of apparent Carboniferous age and shales of that age begin there again. A single specimen of Favosites, of Silurian age, was collected from one

* Principal Events in North American Cretaceous History as revealed in the Arkansas-Texas Region, by Robt. T. Hill. This Journal, April, 1889.

† Professor Alpheus Hyatt, to whom I sent this specimen, says that he thinks there is little doubt that it is a fragment from the Hudson River group. The Orthoceras being closely related to one found at Cincinnati, and the brachiopod being probably *Orthis testudinaria*.

of the Delaware Mountains near the Hudson River limestone. The Delaware Mountains proper are a few long limestone ridges and detached buttes in the beautiful valley of Delaware Creek. Seven miles west of the academy, near Bill Jackson's, they are composed of limestone underlaid by the above mentioned Favosites sandstone—a porous gray quartzite with an occasional patch of limestone. The buttes are peculiarly distorted, their strata being disturbed at a very slight angle in many directions, which may be compared to the uneven curvature of a saddle.

The Delaware mountains were mentioned by Mr. Jules Marcou, who followed the old Fort Smith and Fort Washita trail which passed by them. He referred them to the Sub-Carboniferous or Mountain Limestone.* The scenery in the Valley of the Delaware is exquisite, the contrast between the low rounded hills and the extensive valleys with their peculiar buttes present a restful and varied landscape. The region promises rich scientific treasures to some future student who has time and facilities to work out its structure and history. It was impossible to trace the relation of the Wapenucka district to the Arbuckle Mountains to the westward, owing to dangers of exploration in a country where geologists are not welcome, but there is evidently a close connection if not continuity between them.

2*b*. *The Tishomingo Granite.*—In the heart of the Chickasaw nation south of and underlying the Wapenucka limestone district is an extensive granite area. This is the central division of our mountain region. It is a triangular area of sandy prairie land with low rounded granite hills and undulations, lying between the Santa Fe and M. K. and T. railroad and running east and west from Boggy depot to six miles west of Tishomingo, and northeast to Mill Creek and beyond.

The granite is well displayed two miles southwest of Boggy station; in Pennington Creek; at Tishomingo and other places. At its eastern outcrop it is composed of red feldspar, white and black mica, quartz and hornblende with numerous pegmatitic veins. Its composition and occurrence is nearly identical with the Burnet Texas granite, and it is unlike the igneous rocks of the Wichitas to be described later. In the western part of this area the feldspar is albite. There are numerous dikes of black rock intersecting this granite specimens of which from Pennington Creek have been sent to Professor J. F. Kemp for study. Concerning these he says: "They are a typical diabase. They are mostly idiomorphic plagioclase crystals, doubtless labradorite from the extinction angles, irregular greenish augite and a little magnetite. They show the so-called ophitic

* Geology of North America.

structure of diabase in a very marked degree." The dikes run west 20° S. and are seen at the crossing of Mill Creek road and Pennington Creek.

The northern margin of the granite area is overlaid by hard metamorphosed, sub-horizontal Silurian limestone of the same cherty and flaggy lithologic aspect as the Upper Potsdam rocks of Burnet County, Texas, but I could find no fossils. Carboniferous rocks cover its eastern point at Boggy station. Its southern border was the sea-shore of the ancient Trinity and other Mesozoic and Cenozoic seas and is buried beneath the Trinity sands. The western border is covered by Silurian and Carboniferous rocks.* I saw no evidence that this granite was of later age than the oldest of the Paleozoic rocks which rest upon it.

2c. *The Arbuckle Folds*.—West of the Washita River the mountains again present a new and entirely different aspect. An elongated mass of low rounded barren limestone folds stands about 500 feet above the plain and extends east and west, between Wild Horse Creek and the Washita River for about forty miles, forming an almost impassable barrier for wagon travel. They are composed of folds of hard Silurian limestones. The trend of the mountains—north of west—corresponds with strike of the folds, but is opposite in direction to the prevalent trend of the Choctaw-Arkansas division. These folds are the hard persistent core of the structure, the softer and exterior Carboniferous layers having been eroded to the level of the Ardmore prairies. (See figures.)

West of Duncan the limestone hills are buried beneath the red beds for twenty miles, but again appear in the neighborhood of Fort Sill forming a low ridge north of and parallel to the Wichita Mountains, as is explained later.

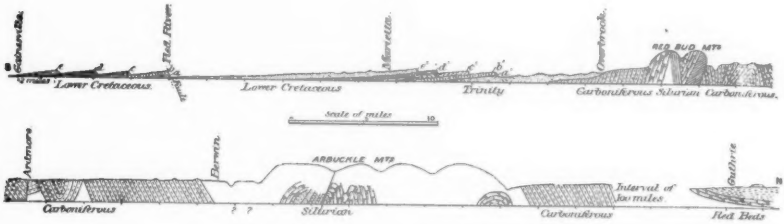
The Arbuckle Mountains constitute a great and wonderful development of the Silurian system, although this has not been hitherto appreciated, and afford a superb example of folded structure. This folding is beautifully shown in the valley of the Washita which has cut a deep and tortuous water gap through these mountains where, unobscured by forest growth, fold after fold of the stratified limestones and shales appear in startling boldness. Several journeys through this gap only increased the appreciation of the greatness of the task of thoroughly delineating the section, the complexity of which may be inferred from the accompanying figures.

Twenty miles south of the Arbuckle ridges proper, and separated from it by a valley based upon Carboniferous shales and sands, near the crossing of Hickory Creek and the Santa

* The only previous mention of this important granite area of which I am aware was made by Dr. R. H. Loughridge in the 10th Census Report on Cotton Production.

Fe road is a smaller but similar and parallel ridge of folded Silurian rocks extending westward to Healdton (see map). For these mountains there is no local name, and I have called them Red Bird from an adjacent post-office. They serve to prove the great width of the folded belt.

4.



Section across Indian Territory from south to north along Atchison, Topeka and Santa Fe Railway.

The accompanying north and south section and profile from Gainsville, Texas, to Guthrie, Oklahoma, gives at least an idea of the sequence and foldings of the Arbuckle region. Proceeding southward along the line of the Atchison, Topeka and Santa Fe, the typical gypsiferous red beds of Texas, Kansas, Indian Territory and New Mexico—the alleged Triassic*—are seen from Guthrie to Oklahoma City, lying in a disturbed, but comparatively sub-horizontal position, showing greater dips than the Cretaceous, but none of the complicated folding of the Paleozoic strata. South of the Canadian, the Carboniferous clays and sandstones appear with the excessive dips of the Ouachita folds. At Buckhorn Creek, east of Dougherty, the coal-bearing beds of the Carboniferous are seen dipping north at an angle of 65°, and involved in the folds of the adjacent limestone hills. In this vicinity there are terranes at the base of the Carboniferous, the age of which I could not determine, especially a great thickness of soft sandstone, but the succeeding limestones are undoubtedly a part of the Silurian system as determined for me from fossils by Professor Henry S. Williams.

Proceeding southward from Dougherty to Berwin the limestones, shales and sandstones of the pre-Carboniferous succeed each other, but so complicated is the vertical folding, that the writer must confess his utter inability to determine their proper succession, even after considerable study. These rocks occupy in cross-section, almost invariably a sub-perpendicular

* The basal portion of these Red Beds is of Permian age as shown in their Texas continuation by Boll, Cope and White. See American Naturalist, June 1879, September 1880.

position for a distance of twelve miles. From north to south, however, the following distinct sub-divisions are apparent.

Their relation however is indefinite, owing to folds and faults:

	feet.
1. Massive, hard blue limestones. Strata of 20 feet in thickness alternating with thin flaggy layers. Thickness (interrupted by a great fault)	+280
2. Massive limestones, but in thinner and more flaggy layers. Cherty	±100
3. Thin shaly argillaceous beds, fossiliferous, excessively folded and crumpled. Aggregate thickness including folds	+360
4. A massive bed of pure white loosely cemented sandstone, similar to that seen above the Lower Helderberg near Woodford	95
5. Thin flags and shales, mostly concealed but seen in contact with 6 at south side of river	?
6. A massive, yellow-blue limestone; finer grained than No. 1; rich in fossils (Trilobites, etc.) South bank of Washita at railroad bridge (Trenton)	+140
7. Concealed interval.	
8. Dark blue shales of great, but undetermined thickness.	
9. Carboniferous shales and sandstone, Berwin to Overbrook.	

Concerning the age of the pre-Carboniferous rocks only a little can be said, but sufficient to confirm the impression that they include Trenton (No. 6), Niagara? (No 1), Lower Helderberg, (No. 2). Could accurate collections be made, many other terranes would no doubt be shown to exist. The basis for these determinations are as follows. Near Woodford post office, ten miles west of the railroad, I collected from strata which are continuous with and apparently the same as No. 2, the following fossils, kindly determined by Professor H. S. Williams: *Spirifera lamellosa*, *Strophomena rugosa* (=*rhomboidalis*), *Rhynchonella nucleolata*, *Lingula? rectilatra*. Concerning these he says: "It is safe to say the horizon is Upper Silurian and probably equivalent to the Lower Helderberg of New York. It is above the Niagara, and this is an interesting feature." Concerning the fossils from No. 6, he says: "They are not very satisfactory but a *Trinucleus concentricus* shows No. 1092*a* to be of Lower Silurian, probably Trenton age." A fine specimen of *Lituites beckmani* Whitfield, in my possession, I have cause to believe came from this same locality, although I had previously been greatly deceived by its collector as to its locality and horizon.

It is not my desire to attempt any classification of these pre-Carboniferous rocks, but I believe from stratigraphic evidence that the shales at the south end of the gap may prove Devonian. Beneath the Trenton rocks there are exposed still older

terranes, especially in the Red Bird Mountains, which may be Cambrian.

Continuing southward along our section the mountains cease coincident with the limestones, and after a mile of black shales (No. 7) the well-defined Carboniferous sands and shales begin near Berwyn and continue for twenty-nine miles along the railroad to the vicinity of Overbrook. These all occur in vertical folds, apparently coincident with or at least a part of the same system to which the Silurian limestones belong, but which, owing to their disintegrating character, have been leveled down to a low undulating plain. Ten miles south of Ardmore, the Trinity sands, the base of the Comanche series, rest unconformably against the Carboniferous (the Red beds being absent), and upon these in turn to the southward the sub-horizontal beds of the Lower Cretaceous, which I shall make the subject of another paper.*

A parallel north and south section twenty miles west of the Santa Fe road shows the presence of the Red beds and the absence of the Cretaceous, the latter having deflected southward through Texas.

It is not alone in the mountains of the Paleozoic areas, however, that this remarkable vertical structure is seen, but much of the Carboniferous prairie regions east of the Red beds are based upon it. For twenty miles north from the Red Bird to the Arbuckle Mountains the undulating prairies, void of any high relief whatever, except slight rises where the sandstones prevail, are based upon the almost vertical Carboniferous shales and sands, as shown in our diagrams. The wonderful degradation these folds must have undergone exceeds all possibility of description. Yet, as I have shown in my Arkansas report, there are many miles of planed-off folds buried beneath the Cretaceous sediments. This is the only instance in the southwest of a level upland plain underlaid by vertical structure. The great unconformity of sedimentation between the Silurian rocks and the supposed base of the Carboniferous is seen both at Buckhorn on the northern margin of the Silurian and at Hickory Creek near Red Bird on the southern side, as shown by difference of dip, and the presence of conglomerates in contact with the Silurian rocks, especially at the last-named place.

3. *The Wichita Division.*—The Arbuckle folds west of Duncan are buried beneath the Red beds for some thirty miles, but outcrop again some eight miles north of Fort Sill, marking the northern margin of the Wichita Mountains, forming a low foothill which is comparatively inconspicuous, owing to the overshadowing height and sharpness of the adjacent eruptives of the Wichita Mountains proper.

* See vol. ii, pp. 503–528, Bulletin Geological Society of North America.

These mountains rise abruptly above the level of the Red bed prairies, which surround them on every side, and their sharp jagged outlines present striking and exquisite scenery. The ragged peaks of igneous rock present a strong contrast to the stratified ridges of the eastern and central divisions of the system. Although in Arkansas the latter have a similar elevation above the surrounding plain, they have not the rugged peaks and points of the Wichitas, and are covered by forests. Their aspect is Appalachian—the arid Wichitas remind us of the Rockies. The eastern Ouachitas are the eroded remnants of stratified rocks with their characteristic topography, the Wichitas consist of igneous rocks—hard, firm, ragged and barren.

These mountains extend westward from Fort Sill 120 miles to the 100th meridian and were partially mapped out by Marcy and McCleland years ago,* and T. B. Comstock has recently made an interesting reconnoisance of them.† The most prominent of the many peaks are Mt. Scott and Mt. Sheridan; the former is 2400 feet above sea level, 1200 feet above Fort Sill on the plain below, and 1700 feet above Red River fifty miles distant. Though neither high nor extensive, the Wichitas are models of topography and mountain structure. Mt. Scott is a solid mass of red feldspathic granite with little quartz, while neighboring mountains are composed of greenstones, basalts, etc., indicating two widely different types of igneous rocks.

The westward continuation of these mountains is buried beneath the Tertiary sediments of the Staked Plains and with it the history of the relation of the Ouachita system to the Rocky Mountains. At one or two places in No Man's Land and north of Clarendon, Texas, I am told that erosion has cut down to the rocks of this mountain system but I have not been able to find the localities.

The composition of the Wichitas is unlike that of any mountain area of the southwest, and, so far as I could see, presents no structural resemblance either to the basin-surrounded mountains of the Trans-Pecos, or the early Paleozoic buttes and denuded folds of the central Texas region. Their age is not determined. They are certainly Post-Silurian and the Red beds have in part participated in the movements but the eruptives may be Post Cretaceous or even later. The apparent absence of the Lower and Upper Cretaceous in the composition of the Wichitas is especially noticeable. Their trend and composition plainly places them in the Ouachita system.

* See Exploration of Red River of Louisiana, Marcy.

† See First (Second) Annual Report of the Texas State Geological Survey. Austin, 1889.

Résumé of History recorded in the Ouachita System.

1. There are evidences of a Post-Silurian movement in the Buckhorn and Red Bird unconformities.

2. The great folding and elevation of the system were after the close of the Carboniferous period, probably during the Permian, as shown by the participation of the rocks of the former period in the movement, and Pre-Triassic, if the upper Red Beds are of that age.

3. A second or lateral movement must have taken place after this folding by which the folds were bent into S-shaped flexures. This movement preceded the Red Bed epoch.

4. The marked but not excessive disturbance of the Red Beds indicates movement and displacement after their deposition and previous to the Trinity epoch.

5. The Lower Cretaceous Comanche series—which may be partly Jurassic—was deposited against and not over these mountains, and show in themselves no folding or other disturbance except such faulting as may be attributed to the Post Upper Cretaceous continental movement.

6. The Upper Cretaceous, the Marine Eocene and the Quaternary along the southeastern and eastern border of the system in Arkansas were also deposited against and not entirely over the system, and, like the Comanche series, reveal no participation in adjacent mountain folding, but merely alternations of subsidence and elevation.

7. This system has undergone extensive erosions throughout Post-Carboniferous time, and its sediments have contributed to all later deposits.

8. The western portion of the mountain system was in parts submerged during the Red Bed epoch [Triassic?] and completely degraded or buried beneath the sediments of the great Tertiary lake which constitutes the formation of the Llano Estacado.

9. The relation of this system to the Rocky Mountain movement is to be determined.

The mountains of the Ouachita system, including the eastern or Arkansas-Choctaw division, the central or Wapenucka Limestone district, the Arbuckle division and the Wichitas, should no longer be omitted from our maps, for together they constitute the foundation of all later geologic structure in the Texas region, differentiating it from the Kansas-Missouri region in both present and past geologic times back to the earlier Mesozoic epochs, and influencing all the main river courses of Indian Territory whose great southward bends are an adaptation to the strike of this mountain system, the Washita alone having cut through it.

The mountains are also interesting from their exceedingly diverse structure and composition, and from the fact that, with the exception of the Uintas, they are the only east and west system on our continent.

Art. XII.—*The Continuity of Solid and Liquid;** by Carl Barus.

Introductory.

1. My earlier papers† entered somewhat minutely into the volume thermodynamics of fluid matter. The behavior of matter passing from liquid to solid and back again was only incidentally‡ considered. This feature, however, is the very one which gives character, or at least a more easily interpretable character, to the whole of the volume phenomena of the substance; and it was therefore reserved for special research.

The problem may be looked at from another point of view: Let it be required to find the relation of melting point to pressure. My results have long since shown§ that in a comprehensive study of this question the crude optical and other methods hitherto used as criteria of fusion (criteria which have no inherent relation to the phenomenon to be observed) must be discarded. In their stead the striking volume changes which nearly always accompany change of physical state, in a definitely constituted simple substance, are to be employed.

The literature‖ of the subject I will omit here, since the more important work has entered the text-books and since I shall probably have occasion to refer to it elsewhere.

The present experiments were made with naphthalene only. They are no means even near the degree of precision of which the applied plan of research admits. Thus far my chief object has been to carry the method quite through to an issue, preliminarily, and to test it at every point. The data are sufficient, however, to show that the procedure adopted, though I approached it with diffidence, can be brought under control throughout; and that the attainable accuracy need only be limited by the patience, skill and discernment of the observer. I was in some degree surprised, therefore, to find that my method led to new results at the outset.

2. *Earlier allied experiments.*—In applying the principle of § 1, I first made direct volume measurements with substances enclosed in capillary tubes of glass. In the case of naphtha-

* Geological interpretations are in the hands of Mr. Clarence King, by whom the work, as a whole, was suggested.

† This Journal, III, xxxviii, p. 407, 1889; xxxix, p. 478, 1890; xl, p. 219, 1890; xli, p. 110, 1891. Phil. Mag., V, xxx, p. 338, 1890.

‡ This Journal. xxxviii, p. 408, 1889; xxxix, pp. 490, 491, 494, 1890.

§ This Journal, l. c. More pointedly with an indication of methods in Phil. Mag., V, xxxi, p. 14, 1891.

‖ I will merely mention Sir William Thomson (1850), Bunsen (1850), Hopkins (1854), Mousson (1858), Poynting (1881), Peddie (1884), Amagat (1887), Battelli (1887) and some others. Cf. §§ 29, 30.

lene and some others, I thus obtained satisfactory results.* Such work is, however, limited to relatively low pressures (600 to 800 atm.); it does not admit of sufficient correction for the volume changes of the glass, and from the small quantity of substance examined, and the relatively frequent occurrence of *nuclear* condensation, volume lags are often obscured. Hence the definition which I was inclined to adopt after making these experiments, viz: that a pressure which when acting isothermally for an infinite time will just solidify the liquid and will just liquify the solid, stands to the given temperature in the relation of melting point and pressure, is not in accordance with facts.†

In a second method‡ I endeavored to ascertain the positions of the characteristic specific volumes by passing current out of the mercury index through the hot walls of the thin glass tube which contained contiguous columns of both the substance and the mercury. Supposing the tube surrounded by a liquid conductor transmitting pressure, the changes of resistance of the arrangement indicate the motion of the index and hence the degree of compression produced. Here, however, a new and unexpected annoyance was encountered, inasmuch as both the medium of oil contained in the piezometer and the glass possess seriously large pressure coefficients.§ Moreover it is only with great difficulty that the perfect insulation of an apparatus, in which water jackets form an essential part, can be maintained. I therefore abandoned the work.

In a third method similar to the preceding, I expressed the motion of the mercury thread or index in terms of the resistance of a very fine platinum wire, passing through the axis of the tube. Successive intercepts thus indicated the changes of volume to be observed. This method gave good indications of the pressure position of the melting points of the sample. It failed, however, to give serviceable values for the fluid volume changes. I found on trial that the contacts in such a case are essentially loose, and that thermocurrents can only with difficulty be eliminated or allowed for, seeing that the successive isothermal temperatures are to be considerably above the atmospheric temperature.

Finally all the methods here described must necessarily fail after the substance has been solidified; for in this case the thread or index is split up and forced into the interstices of the solid material. Thus it is manifestly impossible to retain the

* Cf. this Journal, xxxviii, p. 408, 1889.

† A considerable number of experiments made with naphthalene in this way showed the melting points 83·4°, 92·3°, 100°, to correspond to the pressures 100 atm. 350 atm., 565 atm. respectively. Thus the factor is +·036° C./ atm. § 27

‡ Phil. Mag., xxxi, p. 14, 1891.

§ Ibid, pp. 18 to 24, et. seq.

original meniscus, and therefore impracticable both to arrive at the volume behavior of the solid and to rigorously coördinate successive series of experiments.

3. *Advantages of the method of this paper.*—Hence I endeavored to modify Kopp's* specific volume flask, in a way to make it available under any temperature or pressure. Here the readings are independent of the unbroken character of the meniscus immediately in contact with the solidifying substance, whereas on the other hand (as I shall presently show), the volume measurements can be made electrically,† with almost every desirable degree of accuracy. Furthermore by charging the flask with suitably apportioned quantities of substance and of mercury, the error due to the compressibility of the glass may be eliminated in any degree whatever, and an apparatus be obtained which is practically rigid in relation to pressure. The data show that from each single series of experiments I thus obtain the isothermals and isopiestics and therefore also the isometrics, both for the liquid and for the solid state, admitting the latter to be less accurate; further, the relation of solidification and of fusion to pressure, and finally, the pressure changes of the isothermal specific volumes of solid and liquid, at solidifying and melting points. From such results the character of fusion, and the probable positions of critical, § 26, and of transitional points, § 28, can already be pretty well predicted. It is then only necessary to examine a number of substances, normally existing under widely different conditions of thermal state,‡ in order to broaden the evidence and possibly to reach results of a uniform bearing on matter in general. Thus I endeavor to avail myself of the enormous internal pressure through incremental pressures applied externally.

Apparatus.

4. *Temperature.*—Inasmuch as pressure varies at a mean rate of over 30 atm. per degree of melting point, so that temperature is as it were the coarse adjustment and pressure, the fine adjustment for the conditions of fusion, the method of experiment should be such that temperature may be kept rigorously constant while pressure is varied at pleasure. To obtain constant temperature, I constructed a series of brazed

* Kopp: Ann. Chem. u. Pharm., xciii, p. 129, 1855. The results of this fine memoir are too rarely quoted.

† The absolute expansion and compressibility of mercury being now known. § 7.

‡ "Instead of tracing the isothermals of a single substance throughout enormous ranges of pressure, similarly comparable results may possibly be obtained by examining different substances conceived to exist in widely different thermal states." This Journal, l. c., xxxix, p. 510.

vapor baths of thin sheet iron, thickly jacketed with asbestus. They were cylindrical in form, 20^{cm} high and 10^{cm} in diameter. Axial tubulures, the upper of which projected outward, the lower both inward and outward, allowed the vertical tubular piezometer to pass axially through the vapor baths, and suitable stuffing boxes obviated leakage. Again the upward projection of the lower tubulure (both of which fit the piezometer snugly), formed an annular trough with the walls of the vapor bath, in which a sufficient quantity of the ebullition liquid could be placed, and boiled, by aid of the flat spiral burner below. The top of the vapor bath was provided with two other (lateral) tubulures, one of which served for the permanent attachment of a vertical condenser, and the other for the introduction of a suitable thermometer or thermocouple. Here also the quantity of ebullition liquid present, could at any time be tested, its amount increased or diminished, and its quality directly purified by fractional distillation or otherwise (an operation necessary, for instance, when amyl alcohol is used). § 20. With a good condenser, the boiling may be kept up indefinitely, for the condensed vapor falls back into the trough below. At temperatures below 100°, it is expedient to avail oneself of the high latent heat of water* and to boil this liquid under diminished pressure. Temporarily attaching Professor R. H. Richards' jet pump to the end of the condenser, pressure may be reduced at pleasure, and any boiling point between 50° and 100° reached and maintained indefinitely. For higher temperatures toluol, amyl alcohol, turpentine, naphthalene, benzoic acid, diphenylamine, phenanthren, sulphur, etc., subserve similar purposes more or less thoroughly.

Temperature was measured by a Baudin thermometer of known errors, and also computed from the vapor tension of steam under known conditions.

5. *Pressure.*—To obtain pressures as high as 2000 atm., I employed the screw compressor described elsewhere.† I made use, however, of a vertical piezometer, identical with the horizontal form described, except in so far as it could be removed from the barrel as a whole. As before, the piezometer is insulated from the barrel. When in adjustment the former was surrounded by the following parts, enumerated from below: an insulated guard preventing spilled water, etc., to reach the insulation; the lower cold water jacket, the flat burner, the vapor bath, and finally (wherever necessary) an upper cold water jacket. Internally the piezometer was filled with thick mineral oil.‡

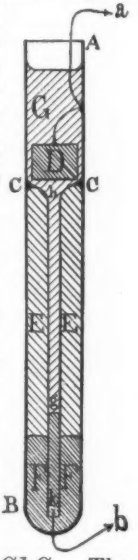
* I shall in future experiments also boil water under pressure.

† Proceed. Am. Acad., xxv, p. 93, 1890.

‡ Phil. Mag., (V), xxxi, p. 10, 1891.

For pressure measurement I am now able to avail myself of superb Amagat "manomètre a pistons libres," which can be attached to my compressor without further mechanism and with advantage.* The instrument is adapted to measure 3000 atm.

6. *The volume tube.*—This is shown in the annexed figure (diagram). It consists of an external cylindrical envelope AB of glass, closed below, open above, about 26^{cm} long and $\cdot4^{cm}$ or $\cdot5^{cm}$ in diameter. Throughout the greater part of its length, the tube is divided into two coaxial cylindric compartments, by a central glass partition tube CkC, open at both ends, and fused to the tube AB along the ring CC, about 7^{cm} from the top. CkC is about 17^{cm} long and $\cdot13^{cm}$ in internal diameter, drawn as thin-walled and even in calibre as possible, so that the greater part of its lower length may be available for measurement.



The substance to be examined is introduced into the annular space EE, care being taken that when fused under the highest temperature and lowest pressure to be applied, its lower boundary may be 4^{cm} or more above the end k. Immediately in contact with EE and extending upward into the central tube is a plug of mercury FF, with its free meniscus at g. When EE is solid, g must be (say) 2^{cm} above the end k, and when EE is liquid g must even in the extreme case be at about an equal distance below the end CC of the tube CkC. The remainder of this tube, above g, is quite filled with a concentrated solution of zinc sulphates Ghg, into which an amalgamated zinc terminal D, has been submerged and fixed in position by the platinum wire a, fused to the sides of the tube AB as shown. The other terminal b passing through the sealed bottom of AB, is in metallic connection with the mercury FF therein contained.

The tube thus adjusted is completely submerged in the oil within the insulated tubular piezometer, with which the terminal a connects. The terminal b completely insulated from the piezometer by a coating of glass tube, is in metallic connection with the barrel. Thus the tube AB is held in position by tensely stretching the fixed wires a and b, and so adjusting their lengths that the parts EE and hg with reference to which the measurements are made, may lie wholly within the *vapor*

* Results thus obtained in comparing various high pressure gauges and methods of manipulation will be given in a current number of the Phil. Mag., xxxi, p. 400, 1891.

reservoir of the cylindrical vapor bath surrounding the piezometer. Many of these operations are delicate, but descriptions must be omitted.

An inspection of the figure shows at once that if a current enter the outside of the barrel, it will pass through *b*, *k*, *h*, *D* and *a*, into the outside of the piezometer, and thence back to the battery. The only relatively significant resistance encountered in such a course, can be confined to the path between *g* and *h*, through the thread of the zinc sulphate solution; but this resistance, cæt. par., varies directly with the length of *gh* and therefore proportionally to the volume contraction of the substance *EE*. If Kohlrausch's method* of intermittent currents, bridge and telephone be used for the resistance measurement of the electrolyte, solidification or fusion of *EE* breaks upon the ear with a loud roar, whereas the ordinary volume changes (solid or liquid) are indicated by intensifications of the sound in the telephone, sufficiently pronounced however to subserve the purposes of measurement.

It is seen that any breakage of the surface of separation between *EE* and *FF* is entirely without influence on these results, and that even in case of solidification of *EE*, when the mercury is forced into the interstices left after contraction, the compressibility of *EE* will still be measurable.

The charging of the tube free from air, is an operation which I have not yet accomplished satisfactorily. If a volatile substance like naphthalene be filled into *EE* and fused in vacuo, vapors objectionably condense in the tube *hk*. If *EE* be not fused, I doubt whether the air can be eliminated in vacuo. Hence in the present work, the substance was not air-free, a condition to which I gave less attention because I do not believe the melting points are appreciably influenced by dissolved air, nor that the other measurements made are seriously distorted by this error. In further measurements, however, I will endeavor to meet the difficulty by fusing the end *A* of the *inverted* tube *AB*, to the top of a barometer tube, provided with a lateral tubulure leading to a Sprengel pump. If then, after exhaustion the lower meniscus is adjustible, so that the whole barometric column can be raised quite into the tube *AB* or withdrawn from it at pleasure, a thorough vacuum filling may be effected. Rubber connections must be scrupulously avoided.

Method of Measurement.

7. *Constants of the tube.*—In order that the present measurements may be carried out absolutely, it is necessary to

* Kohlrausch: Verh. med. phys. Ges. Würzburg, xv, p. 1, 1880; Wied. Ann., xi, p. 653, 1880. Long: Wied. Ann., xi, p. 37, 1880.

know: (1) The volume of the charge at a fiducial temperature and pressure; (2) The volume of the plug of mercury under the same conditions; (3) The volume of the central tube *kh* (figure 1) per centimeter of length; (4) The resistance of the thread of zinc sulphate solution, per centimeter of length, under all the stated conditions of temperature and pressure. From (3) and (4) there follows at once (5) the resistance of the thread of zinc sulphate per unit of volume, under any stated conditions of temperature and pressure. Thus it is necessary to investigate preliminarily (6) the isopiestic relation of resistance and temperature of the given concentrated solution of zinc sulphate, and (7) the isothermal relation of resistance and pressure of the same solution. In other words one must know what may be called the isoelectrics of the measuring electrolyte. Furthermore it is necessary to find (8) the compressibility of the glass in its relation to pressure and temperature and (9) the compressibility of mercury under the same conditions; finally (10) the thermal expansion of the glass and (11) the thermal expansion of mercury under given conditions of pressure.

The measurements (8) to (11) I have not thus far made directly. They are here of small importance, seeing that the substances on which I operate are all characterized by relatively large volume changes. Such measurements, however, are easily feasible, since both the expansion constants and the compression constants of pure mercury (thanks to the recent labors of Tait, Amagat* and Guillaume) are now thoroughly known, and it is also known that the thermal changes of the elastics of glass are of no relative consequence,† even as far as 200°. If therefore the tube *AB*, figure 1, be filled with mercury, replacing the substance *EE*, the expansion and compression constants may be found by the method above stated, §3, once for all. In the present paper I assumed the compressibility of my glass‡ to be ·0000022, that of mercury,§ being ·0000039; moreover the coefficient of thermal expansion of the glass‖ to be .000025, that of mercury¶ between 60° and 130° being ·000182.

8. *Volume of the charge.*—Clearly the fiducial conditions to which the volumes are to be referred, are given by the (normal) melting point, under atmospheric pressure. By weighing the tube before and after charging, I found for the mass of naphthalene enclosed, ·763*g*. In a special and duplicate set of pycnometer measurements, I furthermore found for the density of fused naphthalene at 82°, ·724. Hence the volume of the

* Cf. E. H. Amagat: Ann. ch. et phys., VI, xxii, p. 95, 1891.
† Ibid., p. 136. ‡ Ibid., p. 125. § Ibid., p. 137.
‖ Landolt u. Boernstein's tables, 1883, p. 69. ¶ Ibid, p. 37.

charge at 82° is ·552 cm³, which I took for the volume at the normal melting point (80°).

9. *Expansion and compressibility of envelopes.*—The plug of mercury weighed 7·74 *g*. Its volume was therefore ·571 cm³, at 20°, and its mean volume between 60° and 130° (being between ·575 and ·582) sufficiently near ·58 cm³.

Thus the volume of the glass tube containing both the charge of naphthalene and of mercury, was 1·13 cm³. Its expansion per degree centigrade ·000028 cm³, while the expansion of the mercury in place was ·000105 cm³, per degree, whence the apparent expansion ·00007 cm³ per degree. Therefore if in place of the fiducial volume ·552 cm³ (§ 8), the following volumes be substituted, viz:

60°	·5565 cm.³	100°	·5535 cm.³
80°	·5550	120°	·5519
90°	·5542	130°	·5311

the tube may be treated as free from thermal expansion. Here at 80°, ·555 appears instead of ·552, to allow for the fiducial volume of the stem *kh* (fig. 1), as will be shown in § 17.

Again the compression of the 1·13 cm.³ of glass, and the ·58 cm.³, of mercury will be:

100 atm.;	glass, ·00025 cm.³;	mercury, ·00023 cm.³;	difference, ·00002 cm.³
500	124	113	11
1000	249	226	23
1500	373	339	34
2000	497	452	45

Thus the corrections which would individually be appreciable (affecting the increments say 3 per cent) are differentially negligible (.3 per cent) where they fall below the electrical pressure coefficient of the zinc sulphate solution. §14, cf. §3.

10. *Resistance measurement.*—Using the interrupter and telephone (§6), I facilitated audition by connecting the diaphragm cup with a graphophone tube, and listening with both ears. The resistances, however, were rather higher than contemplated in Kohlrausch's method, when an ordinary Bell telephone is used. Hence the measurements particularly near and in the solid state are far below the limit of attainable accuracy. I shall in future measurements wind a telephone specially adapted for my purposes, and endeavor to use both ends of the magnet to actuate diaphragms. When zinc sulphate is enclosed between terminals of zinc, continuous currents and the galvanometer are available. In this way, I made most of the calibration measurements. Supposing the mercury index to be slightly deadened in its electronegative qualities by zinc, it may also be used in case of the tube.

Should the measuring thread of mercury *gk*, figure 1, break into parts alternating with threads of zinc sulphate (a possi-

bility when the thread is worked up and down many hundred times, particularly in view of the suddenness of solidification), the constants of reduction are not thereby necessarily vitiated, always supposing the number of such breaks to be small. The shifting of coördinates thus produced can be corrected by check-work at a given temperature.* Long continued passage of intermittent currents, charges the mercury with zinc, but solution of mercury can not become serious, since the column is being continually washed by the terminal *D*. Some advantage would be gained by using zinc sulphate in the strength (1·286, Kohlrausch) which corresponds to maximum conductivity.

11. *Calibration.*—The tube *hk*, figure 1, being of insufficiently uniform caliber, volume must be expressed as a function of length. This I did by weighing threads of mercury, whose length had been measured in successive parts of the tube, obtaining the results of the first two columns of table 1. The fiducial zero is here arbitrarily placed 2^{cm} below the ring *CC*.

Similarly the resistance of the filament of zinc sulphate *hg* must be expressed as a function of length, referred to the same fiducial zero, at some convenient atmospheric temperature. To do this, I drew a zinc wire down to a diameter slightly below the caliber of the tube. Opening the bottom of *AB*, and closing the top so as to hold the terminal *D* firmly in position, I inverted the tube and quite filled it with the solution. *AB* was then placed in a cold water bath, with the terminal *a* insulated, and the terminal *b* replaced by the zinc wire referred

TABLE 1.—*Volumes per unit of length. Electrical resistance per unit of length* $\theta=17{\cdot}8°$. *Volume per unit of resistance* $\theta=17{\cdot}8°$.

Length.	Volume.	Length.	Resistance.	Resistance.	Volume.
cm.	$cm.^3$	*cm.*	*ohms.*	*ohms.*	$cm.^3$
3·00	·0491	−·06	2720	2800	·0000
11·15	·1609	2·13	5780	5530	·0350
4·45	·0715	4·75	10190	8850	·0640
9·79	·1430	7·96	16200	12530	·0920
15·42	·2145	12·06	24340	16270	·1190
3·30	·0538	1·38	4630	20250	·1450
7·20	·1076	3·43	7920	24250	·1705
11·40	·1614	6·18	12790	28500	·1960
15·60	·2152	9·00	18220		
2·75	·0470	11·49	23140		
6·10	·0940				
9·65	·1410				
13·40	·1880				

* This I should have done after obtaining Table 9, §21; but the full details of manipulation could not all be foreseen at the outset.

to, and so adjusted that I could slide it up or down and fix it in any position at pleasure. Measuring the distance between the ring *CC* and the free end of the wire, with Grunow's cathetometer, and measuring at the same time the resistance corresponding to this length, I obtained the data necessary for constructing resistance as a function of length, for the temperature of the bath. In this way the second and third columns of table 1 were found.

Combining the results of these four columns by graphic interpolation, I obtained the fifth and sixth columns in which volume is expressed in terms of resistance, at the temperature $\theta=17{\cdot}8°$ with regard to the fiducial mark in question.

12. *Electrolytic resistance and temperature.*—The investigation of this relation is a general problem, quite apart from the

TABLE 2.—*The relation of electrical resistance to temperature and pressure, in case of a concentrated solution of zinc sulphate.*

Temperature.	Pressure.	Resistance.		Temperature.	Pressure.	Resistance.	
° *C.*	*atm.*	*ohms.*	R/R_{100}	° *C.*	*atm.*	*ohms.*	R/R_{100}
*6·3	100	26960	6·060	99·6	191	1237	·990
6·5	100	26960	6·060	99·6	186	1242	·994
66·8	140	6178	1·388	99·6	471	1222	·978
67·3	140	6120	1·376	99·6	448	1210	·968
68·0	140	6050	1·360	99·6	1011	1198	·958
67·8	140	6060	1·362	99·6	981	1203	·962
67·8	140	6075	1·365	99·6	503	1232	·986
67·7	140	6075	1·365	99·6	507	1232	·986
100·0	137	4550	1·023	99·6	126	1262	1·010
100·0	137	4540	1·020	126·0	157	1062	·850
100·0	479	4470	1·005	126·0	157	1062	·850
100·0	469	4480	1·007	127·8	149	1058	·846
100·0	1019	4370	·982	127·8	149	1058	·846
100·0	996	4380	·985	160·5	154	980	·784
100·0	1507	4310	·969	160·5	154	984	·787
100·0	1443	4320	·970	160·5	154	984	·787
100·0	129	4360	·980	‡6·4	138	7440	5·952
100·0	139	4360	·980	6·4	138	7500	6·000
127·6	158	3740	·840	6·4	138	7500	6·000
127·8	158	3730	·838	16·4	147	4980	3·984
127·8	158	3730	·838	16·4	147	5000	4·000
6·5	116	27140	6·100	16·4	147	5020	4·016
6·3	116	27000	6·067	61·3	170	1900	1·520
†6·7	72	7280	5·824	61·3	170	1900	1·520
6·7	465	7090	5 672	61·3	170	1913	1·530
6·7	458	7120	5·700	85·8	180	1359	1·088
6·7	906	7020	5·616	85·8	180	1359	1·088
6·7	830	7020	5·616	85·8	180	1364	1·091
6·7	498	7130	5·704	99·6	189	1247	1·000
6·7	492	7050	5·640	99·6	189	1253	1·002
6·7	139	7190	5·752	99·6	189	1253	1·002
6·7	147	7160	5·728				

* First Series. Diameter of tube, ·13^{cm}.
† Second Series. Diameter of tube, ·30^{cm}.
‡ Third Series. Diameter of tube, ·30^{cm}.

special apparatus used. Nevertheless I made two sets of measurements, in the first of which I determined the resistance of the thread *hk*, fig. 1, between fixed terminals of zinc, when the whole apparatus was kept at successive constant temperature, and under pressures sufficient to insure the condensation of all polarization gases and the presence of a continuous liquid thread of zinc sulphate solution. The four columned table 2 contains these results, where R/R_{100} is the relative resistance at any stated temperature in terms of the corresponding datum for 100° C. At 100° moreover pressures are varied for the measurement of the pressure coefficients discussed in the next paragraph.

In the second and third parts of the table, the above tube *AB* was replaced by a plain straight tube. Resistances are much smaller here, but the column R/R_{100} makes all the data comparable.

If the values R/R_{100} be compared graphically, as a function of temperature for nearly the same pressures, the results of all the series in table 2 are in good accord. Moreover the results for the large interval 6° to 160°, lie on a curve whose form closely resembles an hyperbola. From this point of view the data are remarkably interesting: for if it be true, then a suitable inversion of the locus indicates that the electric conductivity of the electrolyte varies linearly with temperature. Such a result would not only possess theoretic interest, but would make measurements of the kind necessary in the present paper feasible with a high degree of certainty. The interpolations of this paper were made empirically however, and I must withhold further opinion until I can trace the locus as far as 300°. I may add that inasmuch as a solution of maximum conductivity is accompanied by a smaller temperature coefficient, advantages of such a solution are suggested, §10.

13. *Volume in terms of resistance.*—With the data of §§11 and 12 in hand, it is now possible to express the volume of the capillary tube *hk*, figure 1, in terms of the resistance of the thread of electrolyte, observed at any temperature. With this object in view, I computed tables for each of the temperatures of the isothermals below, §§15 to 21, facilitating the further reduction by graphic methods. Being merely of passing interest the tables are omitted here.

14. *Pressure coefficient of the electrolyte.*—The results in table 2 for variable pressure and constant temperature are summarized in the small table 4, below. Here θ denotes the temperature, R the resistance of the thread, and $k = \delta R/R_0 \cdot \delta p$ where p symbolizes pressure, the pressure coefficient sought R_0 holds at 0° *C.*

TABLE 4.—*Pressure coefficients of concentrated zinc sulphate solution.*

θ	Pressure.	$k \times 10^6$	θ	Pressure.	$k \times 10^6$	θ	Pressure.	$k \times 10^6$
7°	119 }	−43	100°	157 }	−64	100°	137 }	−43
	479 }			482 }			1007 }	
	119 }	−35		157 }	−49		474 }	−35
	868 }			996 }			1475 }	

The mean value is $k = -45/10^6$, being negative, inasmuch as the resistance is here decreased by pressure. The pressure coefficient is nearly independent of temperature, and decreases somewhat with pressure. The results, however, are not quite consistent, and a detailed construction of the data in table 2 shows a difference of march in the pressure on and the pressure off movements. I have yet to learn whether this be due to insufficiently fixed terminals, or to polarization, as well as to find the conditions (change of concentration or of the solution) under which the pressure coefficient may be a minimum. As the results stand the mean value is probably within 20 per cent of the truth, and hence in the extreme case of 2000 atm., the uncertainty of the pressure coefficient will not affect the volume increments more than 2 per cent.

In an earlier paper,* I found $k = -50/10^6$ between 0 and 150 atm., agreeing substantially with table 4. I then called attention to the strikingly close proximity of this datum to the corresponding coefficient for mercury $k = -30/10^6$. The pressure coefficient is of considerable interest, inasmuch as it indicates a certain relation between elasticity and the chemical equilibrium of the solid or liquid operated on† specially for zinc sulphate, it may be noted that whereas the conductivity of a nearly concentrated solution (density > 1·29) decreases on further concentration, compression (which might be regarded as having a concentrative effect on the solution between the terminals) increases the conductivity.

Results of the measurements.

15. *Arrangement of the tables.*—The following tables 5 to 10, in which the isothermals of naphthalene are fully given, are constructed as follows: The first column contains the time in minutes at which the observation was made, the initial date being arbitrary. The (uncorrected) resistance as actually found at the pressure given, is shown under R in ohms. To this the correction for pressure coefficient, kp per unit of R, is to be

* This Journal, xl, p. 219, 1890. The work of this paper was done some two years prior to the publication.

† Phil. Mag, V, xxxi, p. 24 et seq., 1891.

added, after which R can be expressed as a volume increment, referred as yet to an arbitrary fiducial zero, §§ 13, 14. The corresponding volume (last column of the tables) is deduced from this by inserting the initial volume values of §9. Cf. §17.

Two data are usually given for each step of pressure, the second of which, obtained after long waiting (5^m or more) is more nearly isothermal than the first. In most cases, a small additional volume decrement takes place after solidification, either viscously or as the results of gradual decrease of temperature.

Parentheses occur to show that for the data enclosed the measurement was made along an (upper) part of the tube *hk*, figure 1, whose calibre was not sufficiently uniform. Without knowing the full expansions at the higher temperatures and lower pressures, it is a priori impossible so to fill the tube that all measurements fall within calibrated parts, and all other calibration conditions are complied with, §9. These approximations however refer to the liquid state, and are thus of less consequence in this paper, §1. If the isothermals of the liquid only were sought, it would be advisable to make the tube *hk* very much more nearly capillary from the outset.

The experiments were made on different days, and together extended over more than a week. This is too long a time to employ the tube without special readjustment, and some shifting of coördinates may therefore have occurred. §§10, 25, 26.

I may add finally that the melting point of naphthalene in air is about 80°, its solidification point below this, under proper conditions. The density of the solid is 1·14, and that of the liquid at 82°, is ·724, §8. Hence naphthalene melted in water sinks or swims, according as its temperature is sufficiently below or above 80°.

16. *Solid isothermal*, 63°.—Clearly the data obtained in operating on the solid will be less accurate than the liquid

TABLE 5.—*Isothermals of (solid) naphthalene, at 63·5°, referred to ·55 cm.³, at the normal melting point.*

Time.	Pressure.	R.	$kp \times 10^3$	Volume.	Time.	Pressure.	R.	$kp \times 10^3$	Volume.
m.	*atm.*	*ohms.*		*cm.³*	*m.*	*atm.*	*ohms.*		*cm.³*
16	70	7600	3	·4127	38	859	8240	39	·3965
19	68	7430	3	·4156	40	850	8120	38	·3988
20	289	7760	13	·4085	42	972	8310	44	·3945
23	281	7630	13	·4109	44	966	8310	44	·3945
25	491	8160	22	·4003	46	565	7600	25	·4097
29	481	8010	22	·4027	49	565	7605	25	·4097
34	675	8050	30	·4010	51	100	7270	4	·4183
37	662	7880	30	·4039	67	65	7340	3	·4173

data, §6. For in addition to relatively greater importance of the corrections for the compressibility of the envelopes, the fissured or honeycombed structure and the high resistances, §10, interfere with sharp measurement. Nevertheless by comparing the data with similar solid isothermals obtained at much higher temperatures, their validity may be inferred.

With reference to the series it is interesting to note that recoil of volume (pressure decreasing) is more rapid than compression. The reverse of this would have been anticipated, supposing that mercury lodged in the interstices. The liquid in the above case was allowed to solidify under pressure.

TABLE 6.—*Isothermals of naphthalene, at 83°, referred to ·55 cm.³ at the normal melting point.*

Time.	Pressure.	*R.*	$kp \times 10^3$	Volume.	Time.	Pressure.	*R.*	$kp \times 10^3$	Volume.
m.	*atm.*	*ohms.*		*cm.³*	*m.*	*atm.*	*ohms.*		*cm.³*
36	39	923	2	·5498	79	129	5250	6	·4241
39	226	1183	10	·5371	81	89	4747	4	·4358
44	221	1158	10	·5382	87	93	4348	4	·4453
46	250	1223	11	·5355	94	93	4348	4	·4453
51	244	1198	11	·5365	96	70	3651	3	·4630
53	267	1232	12	·5348	97	70	3256	3	·4732
59	265	1227	12	·5351	104	74	2031	3	·5062
60	303	1288	13	·5322	115	76	1695	3	·5172
63	322	1326	14	·5306	120	75	1480	3	·5250
64	317	5667	14	·4138	122	49	920	2	·5500
73	299	5712	13	·4128	127	52	905	2	·5508
75	127	5250	6	·4241					

TABLE 7.—*Isothermals of naphthalene, at 90°, referred to ·55 cm.³ at the normal melting point.*

Time.	Pressure.	*R.*	$kp \times 10^3$	Volume.	Time.	Pressure.	*R.*	$kp \times 10^3$	Volume.
m.	*atm.*	*ohms.*		*cm.³*	*m.*	*atm.*	*ohms.*		*cm.³*
16	57	773	3	·5542	60	316	4618	14	·4311
18	231	972	10	·5432	65	322	4555	14	·4326
24	222	957	10	·5439	67	280	3855	13	·4504
26	422	1188	19	·5322	73	283	2333	13	·4929
31	406	1155	18	·5338	76	283	1985	13	·5028
33	490	1247	22	·5293	81	278	1618	13	·5152
40	474	1232	21	·5302	83	175	897	8	·5472
42	507	1258	23	·5292	89	179	902	8	·5468
44	532	1288	24	·5276	91	81	793	4	·5530
46	555	5250	25	·4147	95	83	802	4	·5524
57	544	5290	24	·4139					

17. *Liquid-solid isothermal, 83°.*—Three independent series are in hand. The example given in table 6, is the second in number. It is from these isothermals that I obtained the

fiducial zero of the stem *hk*, figure 1. For at pressure zero the increment is ·0024 cm.³. Hence the value ·5524 of § 8, increased by ·0024 is the fiducial volume (·555 cm.³ nearly) here to be used, and from this the others are derived. § 9.

18. *Liquid-solid isothermals at 90°.*—Two independent series of results are in hand. The example given in table 7 is the second in number.

19. *Liquid-solid isothermals at 100°.*—Four independent series are in hand. The example given in table 8 is the second in number.

TABLE 8.—*Isothermals of naphthalene, at 100°, referred to ·55 cm.³ at the normal melting point.*

Time.	Pressure.	*R.*	$kp \times 10^3$	Volume.	Time.	Pressure.	*R.*	$kp \times 10^3$	Volume.
m.	*atm.*	*ohms.*		*cm.²*	*m.*	*atm.*	*ohms.*		*cm.³*
20	116	667	5	(·5575)	148	906	4882	41	·4124
27	116	667	5	(·5575)	150	769	4714	35	·4175
29	281	852	13	·5455	157	772	4714	35	·4175
36	274	835	12	·5464	159	644	4556	29	·4224
45	460	1020	21	·5360	165	652	4556	29	·4224
47	670	1223	30	·5255	167	560	3808	25	·4425
53	653	1198	29	·5266	168	560	3202	25	·4599
56	795	1331	35	·5204	169	562	2846	25	·4707
63	766	1300	34	·5219	171	558	2279	25	·4877
54	808	1353	36	·5195	173	558	1889	25	·5000
69	797	1353	36	·5195	176	558	1600	25	·5102
75	780	1336	35	·5202	178	558	1416	25	·5175
76	818	1370	37	·5185	180	557	1300	25	·5224
85	813	1370	36	·5187	184	552	1174	25	·5280
91	785	1336	35	·5202	187	553	1160	25	·5287
93	856	1415	39	·5167	208	553	1158	25	·5288
102	850	1410	38	·5169	213	546	1160	25	·5287
107	820	1370	37	·5185	216	429	988	19	·5375
108	908	1439	41	·5155	225	430	992	19	·5375
116	888	1439	40	·5155	227	287	845	13	·5459
121	890	1439	40	·5155	235	292	852	13	·5454
122	921	4814	41	·4141	237	81	645	4	(·5585)
133	914	4882	41	·4125	244	86	650	4	(·5583)

20. *Liquid-solid isothermals at 117°.*—The vapor bath in this case was filled with amyl alcohol from which the water had not been extracted. § 4. The results for solidification obtained are worthless, except in so far as they contain specific evidence of certain peculiarities of behavior of an unevenly temperatured tube, referred to below. §§ 25, 27. The data for fusion are in part available. I omit the table.

21. *Liquid-solid isothermals at 130°.*—Four independent series of results are in hand. The example given in table 9 is the second in number.

TABLE 9.—*Isothermals of naphthalene, at 130°, referred to ·55 cm.³ at the normal melting point.*

Time.	Pressure.	*R.*	$kp \times 10^3$	Volume.	Time.	Pressure.	*R.*	$kp \times 10^3$	Volume.
m.	*atm.*	*ohms.*		*cm.*³	*m.*	*atm.*	*ohms.*		*cm.*³
5	151	276	7	(·5811)	78	1907	3926	85	·4099
7	464	495	21	(·5586)	84	1880	3950	85	·4091
11	451	484	20	(·5601)	86	1574	3695	72	·4190
14	921	808	41	·5351	96	1575	3695	72	·4190
18	881	770	40	·5378	98	1463	2876	65	·4480
35	1338	1057	58	·5200	106	1463	1690	65	·4914
37	1336	1057	59	·5200	113	1458	1481	65	·5000
57	1464	1132	65	·5158	123	1456	1490	65	·4996
59	1459	1132	65	·5158	125	1245	1021	56	·5220
61	1581	1225	74	·5109	131	1244	1021	56	·5221
63	1656	1278	74	·5083	135	990	845	44	·5327
64	1651	1262	74	·5091	139	994	850	44	·5325
65	1737	1329	78	·5057	141	565	565	25	(·5536)
68	1723	1320	78	·5061	145	580	570	26	(·5531)
71	1794	3878	81	·4119	148	155	275	7	(·5811)
76	1777	3926	79	·4106	153	168	289	7	(·5796)

Deductions.

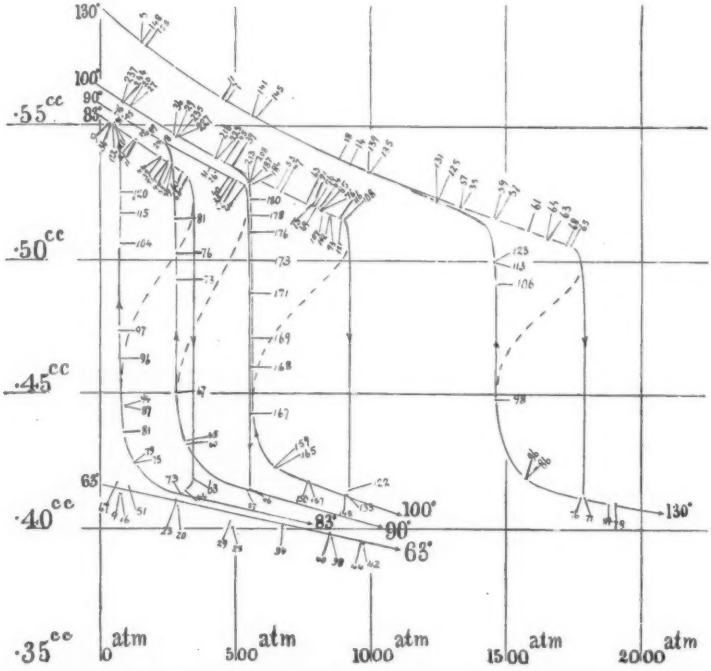
22. *Graphic construction.*—To obtain a survey over this series of individual data, it will be necessary to resort to the pictorial method, and to represent volume as a function of pressure, under the successive conditions of constant temperature. This has been done in the following chart. The ordinates are volumes (fiducial volume being ·5524 cm.³ at 80° nearly, and arbitrarily chosen), the abscissas are pressures. The temperatures of the isothermals are given at the beginning and the end of each curve; and the dates or times in minutes at which the individual observations were made, are shown by small numerals attached to the points. Thus it is easily seen whether an observation was taken during the *on* march or the *off* march of pressure; but to further facilitate inspection arrows are subjoined to the curves, showing their drift.

It is seen from these figures, that the solid is comparable in compressibility with the liquid. On this point, however, I shall now place no stress, for reasons repeatedly stated in the above paragraphs. §§ 4, 16.

23. *Hysteresis.*—The inherent character of all these curves is phenomenally cyclic, the isothermal pressure necessary to solidify naphthalene being at all temperatures decidedly in excess of the pressure at which it again liquifies. Thus the results which I obtained in other experiments and with other substances, some time ago,* are emphatically corroborated.

* This Journal, xxxviii, p. 408, 1890. The full paper and deductions made therein are as yet unpublished.

Evidences of the thoroughly static character of these phenomena are abundant, I mention: solid isothermal 100°, first series (not given above), where I waited from 50^m to 100^m at a pressure below the solidifying point of the liquid, without obtaining fusion, whereas, after this fusion is completed between



101^m and 112^m with only slightly further reduction of pressure; liquid isothermal 100°, second series (given above § 19, and chart § 22), where I waited from 47^m to 121^m at a pressure greater than that at which the solid fuses, without obtaining solidification, whereas this sets in at once between 121^m and 122^m, when the pressure interval is only slightly increased; solid isothermal 130°, second series, where I wait from 86^m to 96^m at a pressure below the solidifying point without change of volume or fusion whatever, etc. If high temperature conditions are unfavorable to volume lag, this evidence and much else which I might add, is accentuated.

I have already pointed out* that it is a phenomenon inherent in the passage from one molecular condition to another,

* This Journal, l. c., Phil. Mag. (V), xxxi, p. 27, 1891.

which lies at the root of all manifestations of hysteresis, whether observed electrically (Cohn, Ewing, Schumann), or magnetically (Warburg, Ewing), or as a purely mechanical result in my work,* during fusion, as above, during solution, § 29, etc.

24. *James Thomson's double inflections.*—Solidification almost always sets in at once. One would expect this: for if there be condensation or crystallization at any one point, it will form the nucleus from which the whole column will be solidified, so far as it lies in the field of volume lag. Only in one case (liquid isothermal 83° 60^m to 63^m) did I obtain evidence of curvature. Usually even at low temperatures the path is precipitous, because pressure cannot be lowered rapidly enough.

The reverse of this holds in case of fusion. Here the initial or stable contours of James Thomson's circumflexures are well marked. It is true that fusion cannot take place instantaneously, because heat cannot be supplied fast enough. It is also true that if temperature be not quite identical throughout the length of column, fusion will first take place at the hotter planes below, and proceed thence to the top.† In the present experiments, however, the phenomenon occurs with the same uniformity at all temperatures, and is quite pronounced in the steam bath. § 4. Hence, taking into additional consideration the evidence of § 22, I conclude that the initial contours are static and regard them as partially evidencing James Thomson's‡ well known inference relative to the doubly inflected contours of the isothermal paths accompanying change of physical state. When fusion actually sets in, the phenomenon is no longer observable; for the physical parts of the substance now exist in widely different thermal states. In figure 2 the full contours are indicated by dotted lines.

25. *The characteristic specific volumes.*—Mere inspection of the chart, figure 2, shows that the volume at which solidification takes place, *decreases* as temperature increases, while the volume into which the substance solidifies either increases or remains stationary in value. In table 10, I have inscribed the corresponding values of pressure and of volume, observed at the solidification points, in each of my four sets of results.§ The data are plotted in figure 3, the volumes being abscissas, the pressures ordinates. To distinguish the points of this diagram, they are surrounded by little circles, to which the number of the series is attached.

A similar and equally expressive table may be deduced by finding the characteristic volumes at the successive melting

* Cf. my results on the Bourdon gauge in a current number of the Phil. Mag.

† I have actually observed this in glass capillary tubes, when the vapor baths were imperfect. ‡ James Thomson: Phil. Mag. (IV), xlii, p. 227, 1872.

§ The above tables and figure 2 exhibiting but one of these sets.

points; but as these data are identical in purport with those of table 10, and since the melting volume is necessarily less easy of definition, § 23, I will omit them here.

TABLE 10.—*Volumes solid and liquid at the solidifying points, varying with pressure.**

Series.	Temperature 83°.		Temperature 90°.		Temperature 100°.		Temperature 180°.	
	Pressure. Solid volume.	Pressure. Liquid volume.	Pressure. Solid volume.	Pressure. Liquid volume.	Pressure. Solid volume.	Pressure. Liquid volume.	Pressure. Solid volume.	Pressure. Liquid volume.
I	260	260	550	550	875	875	1720	1720
	·415	·534	·413	·523	·416	·510	·415	·505
II	320	320	555	555	920	920	1790	1790
	·415	·530	·415	·527	·413	·515	·412	·505
III	345	345	550	550	870	870	1665	1665
	----	----	418	----	·413	·510	·417	·507
IV	----	----	----	----	900	900	1720	1720
	----	----	----	----	·412	·517	----	·505
	----	----	----	----	----	----	----	----

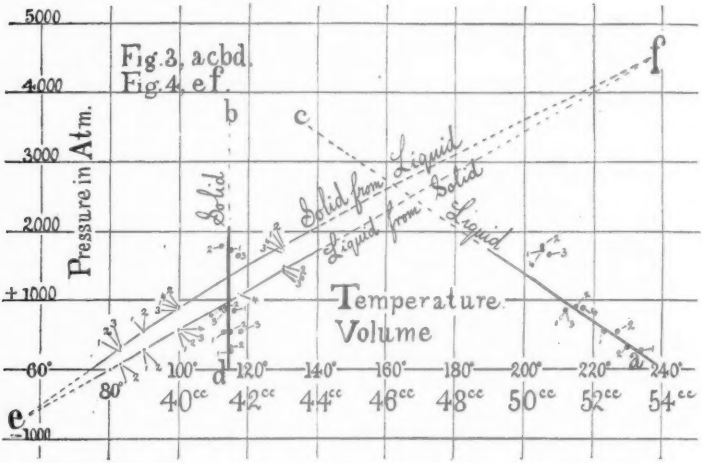
A noticeable feature of the diagram is the closer accordance of the three groups of points between 0 and 1000 atm., during which measurements steam was used as the medium of constant temperature, as compared with the single group of points between 1000 atm. and 2000 atm., when vapor of amyl alcohol was used. I account for this by supposing solidification in the last case to have been premature, and associate the result with insufficient constancy of the vapor bath. §§ 4, 20, 23. Hence, the liquid volumes found are too large. There may also have been some gradual change of the constants of the volume tube, which in the lapse of time became appreciable. §§ 15, 10. Further experiments must decide this point. Regarding solid volumes it is clear that no device can define them as closely as the liquid volumes; indeed the degree of definition attained is one of the virtues of the method. § 16.

In figure 3 I have therefore placed chief reliance on the water points (0 to 1000 atm.) and drawn the locus accordingly.

26. *Critical point.*—The area enclosed by the lines *ac* . . ., and *bd* . . ., supposing *b* and *c* eventually to coalesce, has the same signification as Andrews's area of vapor tensions. This would also be true of the similar figure for the characteristic volumes at the melting points, and more pointedly of the figure in which solidification volumes are taken at the solidifying points and fusion volumes at the melting points. § 25. All of these diagrams point out the probable occurrence of a *critical point in the region of positive pressure, reached in the direction of increasing temperature,* at which point solid would change to liquid and liquid to solid, without paroxysmal change

* See remarks on table 11, § 27.

of volume, and consequently without volume lag. In case of naphthalene the position of this point may be conjectured at several hundred degrees centigrade and several thousand (5000 to 10,000) atmospheres.



27. *Solidifying points and melting points.*—The cycles depicted in figure 2 have two prominent characteristics: They gradually decrease in vertical extent from left to right and they gradually decrease in lateral extent from a central area toward both sides of the chart. The former quality has already been interpreted. §25, 26. The latter is now to be considered.

TABLE 11.—*Showing the relation of solidifying point and of melting point to pressure, at different temperatures. Naphthalene, melting at* 80°.

Series.	Temperature 83°.		Temperature 90°.		Temperat're 100°.		Temp. 117°.	Temperat're 130°.	
	Solid at	Melting at	Solid at	Melting at	Solid at	Melting at	Melting at	Solid at	Melting at
	atm.	*atm.*	*atm.*	*atm.*	*atm.*	*atm.*	*atm.*	*atm.*	*atm.*
I	**a*260	80	*a*550	275	*a*875	560	----	*a*1720	1430
II	**b*320	80	*b*555	280	*b*920	560	----	*b*1790	1465
III	*a*345	--	----	----	870	580	----	†1665	1410
IV	----	--	----	----	*b*900	570	1050	*a*1720	----

c { Factor: M. P. and pressure, 80° to 130°, 28·5 *atm.*/°C., or ·0351 °C./*atm.*
" : S. P. " " 80° to 100°, 36·0 *atm.*/°C., or ·0278 °C./*atm.*
" . S. P. " " 100° to 130°, 29 5 *atm.*/°C., or ·0339 °C./*atm.*

a, Not crept upon. *b*, crept upon. *c*, Factors taken chiefly with reference to series II.

* First result at <83°, second and third at >83°. Solidification gradual, the other solidifications take place at once.

† Temperature 129·6°.

Table 11 gives the values of the pressures corresponding to solidification and to fusion at the different temperatures, together with other relevant information, as sharply as these statements can be made. M. P. denotes melting point, S. P., solidifying point.

Let the solidifying points and melting points be constructed as functions of pressure. Figure 4 shows the points to lie on a spindle-shaped figure, running diagonally across the chart. They are again taken out of all the four sets of results and numbered accordingly. § 25. The parts of the curves actually observed are given in full lines, the inferential prolongations in dotted lines.

From the nature of the case the solidification points are not sharply determinable. § 23. Even leaving the nuclear solidification induced by inconstancy in the linear distribution of temperature out of sight (a marked example of which occurs in the series for 117°, § 20, where solidification and fusion are practically coincident), all percussion and jarring, too rapid increase of pressure, a vibratile wire running through the column as in some of my earlier experiments, will cause the whole labile structure to topple into solidification. Hence the solidifying points must be fairly *crept* upon and surprised, and hence my present results in which these precautions were taken show high solidifying points as compared with my other work. § 2, note.

These conditions do not hold with like importance in case of fusion; for the melting points as a rule show much greater coincidence.

In figure 4 I have therefore placed chief reliance on the data of series II obtained as they were with the experience of series I to guide me.

28. *Transitional point.*—If the two curves be prolonged in the direction of *increasing* temperature, their eventual coalescence is presumptive by §§ 25, 26. Clearly the occurrence of volume lag must cease when the paroxysmal volume changes vanish.

If the two curves be prolonged in the direction of *decreasing* temperature, then the data themselves indicate the probability of an intersection in the region of negative pressure. Beyond this, therefore, there would be an inversion of the conditions of fusion: in other words, the substance would solidify at a lower pressure than that at which it fuses, and fuse at a higher pressure than corresponds to solidification. I believe this remarkable suggestion to be interpretable as follows: The normal type of fusion changes continuously into the ice type of fusion, through a transitional type, characterized by the zero of volume lag. The position of the latter for naphthalene, so far as can

now be discerned, may be placed at (say) 50° and (say) −1000 atm. It is noteworthy, that with the understanding here laid down, the normal type of fusion is reached from the ice type, in the direction of increasing temperature.*

29. *Solubility and pressure.*—In view of the detailed analogy which holds between many characters of fusion, and of solution, much that can be investigated for the simpler of these phenomena (fusion apparently) will be applicable to the other. A substance may be transferred from the solid into the liquid state either (1) by heating it, or (2) by dissolving it. In general, excess of temperature, or of solvent favor the diminution of viscosity here in question. A liquid on the verge of solidification or a concentrated solution is solidified or deposits solid on cooling; and in both cases the nice adjustment of labile molecular equilibrium is accompanied by volume hysteresis,—under-cooling, etc., in the one case, supersaturation, etc., in the other. Hence I conclude that if under proper thermal conditions pressure alone can solidify a liquid, it can also under proper solutional conditions induce crystallization or the deposit of solid from solution—thereby trenching upon, or (from a new point of departure) approaching the modern chemical doctrines which originated, I believe, with van't Hoff.

I am the more justified in drawing these inferences as in my last article† on the solvent action of hot water on glass, I have already adduced the necessary evidence. Since from one point of view, the isothermal compressibility of silicated water is increased proportionally to the time during which the solvent action has been going on; and from another, with the amount of basic silicate dissolved,—the deduction is closely at hand, that what pressure actually did in this instance, was a mere precipitation of a proportionate amount of the dissolved silicate. The volume changes thence resulting were blindly put into computation as increments of compressibility, because the precipitated silicate is again dissolved when pressure is withdrawn.‡

* [*Added to proof.*—Throughout the present paper, I have avoided the discussion of the isopiestics, since I shall consider them in detail in connection with special experiments. It is well to state, however, that the transitional temperature is related to the prospective intersection of the prolonged liquid and solid isopiestics, of a given substance, at the same pressure in both cases. Thus a reason why hysteresis may vanish is again suggested. A given substance on one side of the transitional temperature would differ molecularly from the same substance on the other side.]

† This Journal, xli, p. 110, 1891.

‡ [*Added to proof.*—In justice to myself let me say that the manuscript left my hands on Feb. 23d, some five months ago, and before the kindred deductions of Orme Masson (Nat. xliii, p. 345, 1891), or of Ramsay (Nat. xliii, p. 589, 1891) had reached me. I have not in any way altered § 29. In fact, what these gentlemen have deduced from the solution behavior liquid-liquid, I had legitimately derived from the solution behavior solid-liquid, as set forth in my own work. My preced-

Thus the work has a bearing on the nature of solution; for to my thinking, what I have ventured to call cohesive affinities* cannot differ except in degree from the affinities determining valency. At least proceeding on this assumption, I am led naturally to a theory regarding changes of the physical state of aggregation in general, which I will indicate elsewhere.

30. *Conclusion.*—In the above pages I have merely sought to describe the results directly given by experiment in so far as I understand them, and to draw conclusions which in the light of known facts seemed to be admissible or even obvious. In how far these conclusions are to stand or fall, will depend on similar investigations, to be made with a variety of other substances specially selected with reference to their position in a scale of thermal state. § 3. How such selection is to be made, I am now unable to intimate. Substances for instance which fuse continually, like glass or sealing wax, might at first sight be referred to positions near their critical temperatures: but I believe these cases are mere solution phenomena of relatively small interest. At all events at the outset, the experiments must deal with bodies of definite, simple and preferably crystalline character, to the exclusion of mixtures. I feel confident that in an examination of many types, some will be found lying relatively nearer the critical point, while others lie nearer or even beyond the transitional point; and that if the above method be applied with greater rigor than was done in the present paper, light will be thrown on the long neglected department of fusion and solution thermodynamics as related to pressure. From this stage of progress it will then be possible to approach nearer the next of the kindred phenomena, which I conceive to be nothing less than the kind of hysteresis or higher order of volume lag known as chemical affinity.

[*Added to proof.*—To obviate the occurrence of a bald statement like the last, I will indicate my views on the distribution, or successive orders of volume lags. These are to be sought—I, during the passage of a given atom into the next consecutive in a scale of decreasing atomic weights; II, during the occurrence of dissociation of the molecule, including solutions gas-fluid. They are demonstrable, III, in the region of Andrews's vapor tensions, including the Alexéef-Masson solutions liquid-liquid; IV, in the region of the solid-liquid phenomena of the present paper, including solutions solid-liquid; V, in the region of solid-solid phenomena categorically distinguishable as "permanent set" (Osmond, Carus-Wilson, Barus). They are to be sought for finally, VI, during the passage of a given atom into the next consecutive in a scale of increasing atomic weights.

The enumeration is systematic, and inasmuch as VI is virtually identical with I, the inherent nature of these changes is periodic. Hence under suitable thermal conditions, and continually increasing pressure, the evolution of atoms, of molecules, of changes of physical state, are successive stages of periodically recurring hysteresis.]

ing paper is at fault only in postulating an unnecessary change of hydration of the silicated water (l. c., p. 116).

It is gratifying to note that evidence of the similar solution behavior solid-solid is forthcoming, and to be found in the work of Osmond, of C. A. Carus-Wilson (Phil. Mag., xxix, p. 200), and of myself, as I have already pointed out (Phil. Mag., xxxi, pp. 26–28).]

* Ibid., p. 115.

Art. XIII.—*Note on the Asphaltum of Utah and Colorado;* by George H. Stone.

During the past year the writer has visited all the known asphalt fields of western Colorado and northeastern Utah, save those situated within the reservations of the Ute Indians, and two other exceptions noted below. It is intended at some future time to complete a map of the asphalt exposures and to publish a more detailed account of them than is possible in this preliminary paper.

Petrography of the Deposits.—The following named classes of deposit are represented:

1. *Asphaltic sand-rock*, known also as sand-asphalt and bituminous rock. This is the most abundant of all the asphaltic deposits. It consists of a sandstone the grains of which are in contact with each other and the spaces between the grains are wholly or partly filled with asphaltum. The proportion of asphalt varies up to about 15 per cent by weight and 27 per cent by volume Of course sandstones will contain different proportions of asphalt in their inter-granular spaces since those spaces depend on the sizes and shapes of the constituent grains and often on the presence of other cementing substances. When a bituminous sandstone contains more than about 15 per cent of asphalt, it may be assumed that it has not been under pressure of superincumbent rock sufficient to cause the grains to come in contact with each other.*

The thickest stratum of fully charged rock that I have seen was near 40 feet in thickness. Usually the strata of high grade rock are not more than 4 to 10 feet thick and they alternate with lower grade or barren strata of sand-rock, and sometimes with marls, shales or limestones. Hence the amount of rich rock,—"pay rock"—has often been enormously over-estimated, no account having been made of the poor strata. This is particularly the case with some of the published accounts of the asphalt beds of the valley of Ashley Creek, Utah.

2. *Bituminous Shales or Marls.*—Black or blackish marls or shales cover large areas both in Colorado and Utah. The richer layers have the smell of asphalt, though like Wurtzilite, they are difficultly soluble. The specimens examined by me

* The analyses of the California bituminous rock given in Seventh Annual Report, Wm. Irelan, Jr., State Mineralogist, Cal., 1887, pp. 51–53, show from 1·10 to 8 per cent of fixed carbon, and of volatile carbonaceous matter from 9·40 to 46·20 per cent, with small proportions of lime, etc. An asphaltic sand containing so large a percentage of asphalt as afforded by some of these analyses would probably have been produced by a relatively small quantity of sand being washed or drifted on to an outflow of soft asphalt.

yield no paraffin, or at most a mere trace to solvents and boiling water, and a considerably larger proportion after destructive distillation. They approach cannel coal in composition, but contain a very large proportion of ash, so that none of them contain more than 10, or perhaps 20 per cent of carbonaceous matter. The richer layers are commonly known in western Colorado as "oil rock," and burn readily with a bright, furious flame, leaving pieces of shale having the same size and shape as they had before being burned. These facts indicate that in their natural state these bituminous shales (they all contain so much lime as to be more nearly marls than shales) are asphaltic rather than paraffinic rocks. The richer layers are seldom more than 4 feet thick and are found in the midst of low grade rocks (shales, marls, and limestones). At one place I noted ten of the rich layers each two to four feet thick, distributed at intervals through about 400 feet of rock.

3. *Bituminous Limestones.*—Limestones and marls constitute a large part of the Tertiary rocks of the region under discussion, i. e. of the asphalt-bearing formations. Almost all the limestones are somewhat bituminous, and some strata will burn like the shales. They are colored from gray to yellowish-brown, light color, rather than blackish like the bituminous shales. Usually they do not contain distinct fossils, but are often oolitic, pisolitic or coarser concretionary, i. e. they are semi-crystalline. Fetid layers are not rare, and some of them are particularly offensive. Cavities in the bituminous limestones are often filled with hard asphalt, in some places taking the form of Wurtzilite, in other places Uintaite. The color of the Uintaite varies from the deepest black to brown and even gray-brown. The lighter colors are found in the centers of the lumps or in the cavities less open to the air. I have found asphalt in five classes of cavities in these limestones.

1. In small irregular or somewhat amygdaloidal cavities in fine granular limestone and having no visible outlets.

2. In fractures that cross the strata for only a short distance (gash veins of the miners).

3. In deep fissures (true fissure veins).

4. In caves or channels of subterranean streams, in which the asphalt was brought in after the stalagmitic growths were completed or nearly so.

5. In the interior of shells, or in the cavities found in the centers of concretions and nodules contained in the limestone.

The limestone yields on destructive distillation several per cent of volatile and combustible carbonaceous matter. In all cases unless in the fissure veins and stream caves it is evident that the asphalt must have been derived from the country rock, i. e. a bituminous liquid oozed out of the limestone into the cavities. Since

the limestone is of a light color, this liquid must have acquired its dark color during the process of being changed into hard asphalt. This conclusion is confirmed by the lighter color of the least exposed asphalt. Evidently the bituminous matter that is now in the rock is not in the condition of ordinary black asphalt, but the liquid which oozed out of the rock was capable of being changed into such asphalt, hence the bituminous limestones may well be classed with the asphalt-producing rocks.

The rather light color of some of these masses of hard asphalt, which have all the properties of Uintaite except the deep black color, suggests the question whether the color of asphalt be not due to disseminated fixed carbon, in a state approaching charcoal, the product of partial oxidation, more than to the natural color of the hydro-carbons proper. I began some experiments and analyses to determine this point, but the work is incomplete.*

4. *Outflow or Overflow Asphalt.*—Under this class are here included all forms of asphalt that have oozed out of the rock that originally contained them. Some of these had the black color before, others have acquired it since the outflow. I leave it as an open question whether these oils were true asphalts before acquiring the black color.†

Mineralogically the outflow asphalts present the same difficulties of classification as do the petroleums. There are perhaps a dozen different grades in Utah and Colorado that might be described as distinct minerals by those on the alert for new species. The more important generic terms (they are all generic rather than specific) are the following: 1. Maltha, asphaltic tar, brea, mineral tar or pittasphalt. Here are included the viscous liquids. In Utah they all have an aromatic odor and black color. By degrees they harden to a solid, sometimes tough, waxy or horny, sometimes brittle. The

* Mr. S. H. Gilson, of Salt Lake, informs me that he has obtained by distillation of the limestone out of which a mass of Wurtzilite had oozed, a dark yellowish tarry material that closely resembles and appears to be identical with the distillate from the Wurtzilite.

† That the lighter constituents of petroleum can be changed to more viscous oils by protracted exposure to oxygen, appears to have been proved by experiments made some years ago by W. P. Jenney. The same conclusion is enforced by the hardening of the brea of California, also by the finding of asphalt in cavities in the Devonian and Silurian petroliferous rocks (see Report of Professor Edward Orton on the Trenton Limestone as a source of Natural Gas and Petroleum in Ohio and Indiana. Eighth Ann. Report Director U. S. G. S., 86–87). Such asphalt cavities have been observed by Shaler, Newberry, Linney, Orton and others. In the present state of the argument it is permissible to assume as a working hypothesis that the harder asphalts were derived from the softer or pittasphalts, and they in turn from more liquid bitumens. under exposure to the air or perhaps to aerated waters. How much this is quantitatively due to oxygen or other chemical agencies, and how much to evaporation of the lighter compounds, remains to be determined

hardened outflow is known as outflow or overflow asphalt. The maltha is found in small pools, or spread over the ground and often penetrates the spaces between the broken rock of the talus or sub-soil in a complex network of stringers, small veins and sheets. 2. Uintaite or Gilsonite. A brittle, easily soluble and fusible mineral. 3. Wurtzilite, a shining, tough mineral, fusible and soluble with great difficulty.*

Geological Age of the Deposits.—A fissure vein of wurtzilite is reported to be found in a region where none of the U. S. geological maps show rocks later than the Jurassic or early Cretaceous, and the same is true of one area of asphaltic sandrock. I have not examined these deposits and leave their age an open question. All the fields of sand asphalt that I have visited are plainly of Tertiary age. Most of them are in the Green River beds, some may be in the upper part of the Wasatch, and the thick beds found in the Ashley valley appear to be near the base of the very late Tertiary formation marked on Hayden's maps as Uinta and on that of Dr. C. A. White, (Ninth Ann. Report Director U. S. G. S., 87–88) named Brown's Park. The black asphaltic or bituminous shales (marls) are of Green River age. The bituminous limestones, so far as I have observed them, are of Green River and some perhaps are of Upper Wasatch age. The outcrop of the fissure veins of uintaite and some of the wurtzilite are in the Brown's Park rocks and therefore these veins were opened and filled after the Brown's Park epoch—obviously in case of outflow asphalt we have to determine not only the date of origin of the tarry bitumen but also the date of outflow. These fissure veins will be referred to again.

The Bituminous Rocks and Coal Beds.—In one place in the Ashley valley a coal bed about two feet thick has an underclay a few inches thick, and that rests directly on the asphaltic sand rock. The coal is a fair specimen of the Tertiary coals of the region. It is free burning, not caking, and no bitumen

* For a full description of Uintaite and Wurtzilite and their relations to albertite, grahamite and elaterite, see article by Professor W. P. Blake, Proceedings of American Institute of Mining Engineers, Feb. 1890. I have recently learned of a locality where the wurtzilite is said to soften under heat so as to be drawn out into strings that tend to shorten. This grade is very near elaterite in behavior and perhaps is identical with it. The Ute Indians have camped on almost all the uintaite and wurtzilite in this country. The valley of the DuChesne River, also those of the Lower White and adjacent parts of the Green River, are crossed by numerous fissure veins of these minerals, though wurtzilite is more often found as an out-flow product in the talus and scattered drift than in fissures. Both wurtzilite and uintaite are found in a great variety of situations. It is uncertain whether the hardening of the outflow into one or the other of these minerals is due more to original differences in the chemical composition of the outflows or to the physical conditions under which they hardened after the outflow. I have not heard of both minerals being derived from the same outflow. So far as at present known the facts seem to indicate that they are derived from malthas of different chemical composition.

has invaded it or its under-clay from the asphalt layer. The coal abounds in lumps of yellow, partially mineralized rosin, just like most of the softer coals of the mountain region.

In the Wasatch and Roan Mountains I have in several places found coal seams up to eighteen inches in thickness with the bituminous Green River shales and limestones both above and below them. Here the conditions for the formation of coal and asphalt rocks alternated.

Both the bituminous rocks and the coal beds are substantially conformable to the bedding, and both are somewhat lenticular.

A few years ago, Mr. C. A. Ashburner proposed as a basis of classification of coals the ratio of fixed carbon to volatile carbonaceous matter. As I understand it the term "fixed carbon" does not assume that all the carbon thus designated exists in the coal as carbon uncombined with hydrogen, etc., but refers to the residue after destructive distillation. It remains to be determined how far this test will apply to the asphalt. In western Colorado and Utah we find in the carbonaceous minerals all proportions of fixed carbon from one or two per cent in the maltha up to eighty-seven or more in the anthracite. The soft asphalts grade by insensible degrees into the hard asphalts (at least in their physical characteristics) and these in turn into jet, the cannel coals and bituminous shales, and these again into the caking coals, etc. Dana's Text-book of Mineralogy approves the theory that coals are chiefly composed of oxygenated hydro-carbons. In the Rocky Mountain region not only must a scientific classification of the coals take account of the oxygen contained in the different coals, but the industrial classification must do the same also. Many coals of this region when once inflamed will continue to burn for a long time even when protected from the air. This accounts for the long distances the lignites often burn under ground. On East Salt Creek, Col., the burning coal produced a layer of slag of unequal thickness up to twelve feet and the country shows the action of hot waters much like a volcanic region. Several places are known where the coal adjacent to the once burning coal has been changed to a natural coke, and as we go backward from the former fire the coke passes by degrees into the unaltered caking coal.

Origin of the Asphalt.—When the facts as to the Utah and Colorado bitumens are thoroughly collated and discussed, they will throw considerable light on the mooted questions as to the origin of petroleum, asphalt, gas, and other subterranean hydrocarbons. Most other areas were marine, while these deposits were made in the sediments of the extensive lakes which in Tertiary times extended from the Rocky Mountains several hundred miles westward. These rocks will therefore present conditions somewhat different from those of marine beds.

My partial exploration does not yet warrant discussion of all the questions at issue but certain points may here be mentioned.

From Professor Orton's report above cited I extract a few statements of theories.

Dr. T. Sterry Hunt counts limestones the principal source of petroleum and denies that it has been produced by distillation from bituminous shales, while Dr. J. S. Newberry finds in the shales the main source of oil and gas, and vigorously opposes the view that limestones are ever an important source of either. Professors J. P. Lesley, I. C. White and J. D. Whitney favor the theory of the origin of petroleum by the primary decomposition of organic matter, while Dr. Newberry and Professor S. F. Peckham favor theories of secondary distillation. Hunt regards petroleum as indigenous when in limestones, and adventitious in the other rocks, as sandstones and conglomerates.

Since petroleum and asphaltum appear to have so nearly the same origin, it is permissible to discuss them in the same connection, especially as Dr. Newberry has referred the origin of the Utah asphalt to the marine Cretaceous black shales (Fox Hills and Colorado groups).*

Regarding the above stated theories we remark:

1. Certain Tertiary limestones of Colorado and Utah now contain considerable solid bituminous matter and once contained a liquid substance which has oozed out of the rock into cavities where it became changed to hard asphalt. The asphalt occurs as a great number of rather small masses and its aggregate quantity is great. This sort of rock is well exposed in the remarkable cañons of Parachute Creek, Col.

2. Professor Whitney refers the Tertiary bituminous minerals of California to organic matter derived from marine infusorians (quoted from Orton). In the Tertiary lakes of the region under description we might expect there would be drift-wood, many diatoms and fresh-water algæ and possibly infusorians enough to contribute considerable organic matter to the limestones. Irrespective of this source of organic matter, there are great numbers of fossil molluscan shells in the limestones. Hence although the lime rocks are in part non-fossiliferous and in part may be composed of lime precipitated from solution, yet we seem here to find evidence of the presence of organic matter within them sufficient to account for the indigenous origin of petroloidal bitumens according to Hunt's theory.†

3. The black bituminous shales are also to be considered in this connection. Certain layers are quite rich in bitumens.

* Dr. Newberry as quoted by Salt Lake Journal of Commerce.

† This hypothesis is strengthened by the highly probable indigenous origin of the petroleum of the Trenton limestone in Ohio and Indiana, Orton, op. cit.

They are distributed through several hundred feet of shales (or marls) and occasional limestones. Each stratum bears its own proportion of bitumen over large areas. The richer strata are not those nearest the limestones and they alternate with low grade strata. There are no veins or highly bituminized tracts leading from the limestones out into the shales, nor any other field evidence that after deposition the shales were bituminized from the limestones. Indeed these black shales are a very impenetrable rock. When veins of asphalt cross both limestones and shales the asphalt has in no place that I have discovered passed out into the shales and super-charged them.

Certain of the shale strata contain great numbers of imprints of deciduous leaves, water plants and insects, larvæ, etc. The carbonaceous matter of the leaves is not in the form of asphalt, but of charcoal or free-burning coal and contains quite a large proportion of fixed carbon. It is thus proved that certain strata contained a large amount of organic matter. As above noted there are occasional thin coal beds in the midst of the bituminous shales, but they do not contain more than the average quantity of bitumen found in the coals of the period. Evidently the conditions for the production of coal are very different from those that produce oil and asphalt, but the surprising thing is that we do not find the two conditions passing into one another by transitionary steps.

Thus there is no proof that the shales were bituminized from the limestones and the coals have only their indigenous bitumen and volatile carbonaceous matter. So far as I have observed, the richer bituminous shales and asphaltic sand rocks are mostly non-fossiliferous and there is no direct evidence of the former presence within them of undecomposed organic matter, except a few shells in the sandstones, and some silicified and ferruginized wood.

4. If, according to the views of Dr. Newberry, the asphalt of the Utah Tertiary beds was derived from the Cretaceous black shales, then it must have passed upward either as a liquid or as a gas.

1. Did the asphalt originate in a liquid that passed from the black shales upward? It is admitted that the black shales contain more or less petroleum, though in general these shales afford only thin films of oil. This may, however, be due to the petroleum having drained off to lower levels during the upheavals incident to the elevation of the mountains. From the top of the Fox Hills rocks to the lowest of the Tertiary asphalt beds there intervene 3000 feet or more of Laramie and Wasatch rocks, mostly sandstone, with thick strata of shales, marls and limestones, also several coal beds, and a very impenetrable iron-cemented sandrock. If a liquid passed up through

these rocks it may have been either by a general diffusion through the inter-granular spaces, or it may have been along fractures or fissures.

Now the coal of this region is no more bituminous than the Laramie and Tertiary coals of other coal fields outside of the asphalt area. The Laramie sandstones of the asphalt area are just like those found outside that area. Nobody has yet reported even one deposit of bituminous rock of Laramie age. It is incredible there should have been any general diffusion of liquid bitumens through so great a thickness of various kinds of rocks, without some of the bituminous matter remaining in those rocks, even after they have drained for ages. Moreover, I do not see why such a supposed ascension of petroleoids should be confined to the area of the Tertiary lakes instead of being spread over all the extensive area covered by the black shales. At Florence, Colo., most of the oil is said to be contained in a stratum of sandstone situated in the midst of the black shales, and if the overlying shale and the Laramie rocks have been sufficient to keep down the oil without a general diffusion into the Laramie sandstones, how could happen such an enormous upward diffusion in the region of the Tertiary lakes?

On the other hand, it may be urged that the oils of the marine black shales passed up along great fissures. The Tertiary lakes in question lay along the southern base of the Uinta Mountains and eastern base of the Wasatch. It is the conclusion of Powell, King and others that the Uinta uplift began at the close of the Laramie period and continued through Tertiary time. Great fissure veins of Uintaite now cross the region south of the Uinta Mountains and the Yampa plateau. The fissures cut down through the Brown's Park, Bridger and Green River beds, and nobody knows how much deeper. The fact that they are situated within 30 miles of where a great mountain range was pushed up to say nothing of the Wasatch uplift to the west, makes it highly probable they go down to profound depths and intersect the marine Cretaceous shales. Did the asphalt or any portion of it come up through these fissures? The details of an hypothesis to this effect would be about as follows: The petroleum of the black shales passed up through the fissures and floated on the surface of the water of the lake. Here it gradually oxidized or at least thickened, acquired a black color and became tarry asphalt. The wind blew it upon the sandy shores where it penetrated the sand. Off shore the mud contained in the water became entangled in the asphalt and sunk, carrying its sticky burden with it.* And even if we assume the indigenous origin of the bitumens

* See description by Dr. Joseph Leidy of the action of the mud of the Schuylkill River, on gas tar. Orton, op. cit.

of the limestones or certain layers of the shales, we may also assume that a part of the bitumens originated as above described, or in some other way from the upward passage of oils through the fissures.

Such an hypothesis certainly accords with some of the facts. The rocks now dip from the Roan Cliffs northward to the DuChesne and White Rivers. The marginal portions of the rocks that were laid down in the Tertiary lake of this region have been removed by erosion. This is the region where a non-conformity would be exposed.* While, then, we do not know with certainty that the rocks at the southern margin of the Tertiary lake near the present course of the Green river dipped northward at the time this lake began to exist, yet it is a very natural supposition that they did so, and that it was owing to an uplift toward the south that the lake was formed. If reservoirs of oil existed in the black shales, a northward dip would tend to prevent their escape southward. And since the supposed fissures would let in the water from the lake as well as let out the oil, it is easy to account for the oil rising to the surface of the lake. The intermittent depositing of the asphalt could then be accounted as due to alternate opening and closing of the fissures, such as would be possible during the great Uinta uplift, or to other accidents of sedimentation.

Now the fissures that are at present exposed are of very late age, being made after the latest rocks were formed in this basin, and after the lake was drained by the Green River, and when the Uinta and Wasatch uplifts were far advanced. It is possible that they are the continuations upward of fissures made in earlier Tertiary time, or we may suppose there were earlier fissures that were at the last covered by the Brown's Park rocks. The present fissures are filled with hard asphalt that once was evidently liquid, and indeed the asphalt grows softer as we go down in the veins and in places is somewhat viscous, even quite near the surface. Where I have examined these veins there is no sign that this liquid has passed out into the wall rock and charged it. The only asphaltic rock exposed in the country bordering the fissures is of very low grade, and there is a very large amount of this impoverished rock in that region. There are no known fissure veins in the country where the asphaltic sand rock is rich. Thus there is no field evidence of the passage of asphalt outward from the fissures, but strong indications that the sand rocks were drained of their maltha to fill the fissures.†

* Such a non-conformity exists at the Grand Mesa east of Grand Junction, Colo., where the Tertiary beds overlie the Laramie.

† At two places in the Ashley valley there are very rich areas of sand asphalt at the foot of slopes of natural dip, as if the maltha had flowed down the slopes

If asphaltic tar as such rose in fissures and sub-aerially poured out over the ground or penetrated the pores of the adjoining sediments, we ought to find the richest areas nearest the fissures. But if oil or asphalt rose to the surface of the lake and then was driven far and wide by the winds and waves, the larger masses of asphalt might be far away from the fissures. The bedding and other structural phenomena would be the same whether this rose from the marine shales through fissures, or was derived from the primary decomposition of the organic matter buried in the sediments of the lake.

The fact that the asphalt was not formed till a considerable depth of Tertiary rocks was laid down, favors the hypothesis that it was derived from organic matter contained in the Tertiary beds. However I leave the matter open; though it must be admitted that thus far I have discovered no field evidence of the passage of oils or bitumens upward from the Cretaceous marine shales to form the asphalts of Tertiary time.

2 Was the asphalt derived from gas brought up to the surface? Professor Orton in the work cited well states the chemical objections to the theory of synthesis of more complex compounds from gas. However it is not my purpose to enter into a general argument, only to note the bearing of the facts discovered in Colorado. There are gas springs on the lower White River. In some places the gas is said to be accompanied by a trace of petroleum, but there is no proof that the one is derived from the other, and there is no deposit of asphaltum forming around the place. I find no field evidence that the asphalt under description originated in gas coming to the surface from below. The surface rocks at these gas springs are the very lowest of the Green River and uppermost of the Wasatch.*

5. Near the Utah line, on the head-waters of West Salt Creek, Col., is a field of sand asphalt which contains concretionary masses of the sand rock cemented with lime and iron, from the size of cherries up to four feet in diameter. The concretions are very compact and impenetrable and are free from asphalt, while the surrounding rock is thoroughly charged

(through the pores of the sand) before it became so hard as at present. In one place a large field of the asphaltic sand rock has been laid bare by erosion. The bed dips about 15°, and under the heat and force of gravity has flowed bodily like a glacier, so as to dip down the sides of ravines of erosion a short distance. Some have described this as over-flow asphalt The flow is not equal throughout the mass, but is more active along certain lines of fracture, so that the upper surface looks like an exposure of basaltic columns, while the prisms are marked one from the other by depressions one to four inches deep that are in some cases partly filled by true out-flow asphalt that has cozed out of the sand. As a body this is a mass of sand cemented by viscous asphalt and having a sort of plastic flow, the units of motion being the prisms except at the prismatic lines where the units are the sand grains.

* Prof. A. Lakes of Golden, Colo., like myself, found no oil at these gas springs.

with it. The concretions must have had their intergranular spaces filled with cement before the asphalt penetrated the pores of the sand around them.

A few miles farther west I found an asphaltic sand rock much cross-bedded. Alternate layers about half an inch thick contained more and less asphalt so that the rock was crossed by darker and lighter bands. The size of the grains of sand was so nearly uniform in the different layers that it did not seem probable some of the layers were originally more porous than others. A better interpretation is that the layers were charged from the surface during deposition of the rock, and the same causes that produced the intermittent deposition charged the layers unequally.

While here asphaltization was probably cotemporaneous with deposition, in the case of the concretionary rock above-mentioned, asphaltization did not take place till after the cementing of the concretions. Geologically this may not have been long. At Thistle, Utah, a sand rock containing molluscan shells is charged with asphalt which has also filled the interiors of the shells. Here the time of asphaltizing is not certain.

In general the small amount of fine sediment and calcareous, ferruginous or siliceous cements occurring with the asphalt in the pores of the sand rock, favors the hypothesis that the rock was charged with asphalt contemporaneously with or soon after deposition, and before it had time to become cemented into a compact, solid rock. All the richer sand asphalt readily softens under heat, proving it has practically no cement but asphalt. Apparently it is the presence of the asphalt that has kept the other cements out. Moreover I do not see how asphaltization of sediments can in general be so nearly parallel with stratification unless the strata were asphaltized successively before new strata were overlaid.

6. Professor Peckham, as quoted by Orton, says: "It seems to me that the different varieties of petroleum are the products of fractional distillation, and one of the strongest proofs of this is found in the large content of paraffine in the Bradford oil under the enormous pressure to which it has been subjected."

Near the same horizon as the most of the sand asphalt are found some thin seams of paraffine, near the top of the Wasatch Mountains. This ozocerite or mineral wax is extractable with solvents and hot water, and therein is quite different from the paraffine that results from the destructive distillation of the bituminous shales of this region. For the fractional distillation necessary to leave the paraffines as residuum, Professor Peckham postulates considerable heat. In the Wasatch area I have failed to find evidence of local metamorphism or unusual heat. The ozocerite beds were deposited after the upheaval of the Rocky Mountains, and before the rising of the

Wasatch. The heat of these revolutions came respectively too early and too late, and I failed to find volcanoes very near. The fact that hard paraffines result from the fractional distillation of petroleum and from the destructive distillation of coals and asphalts would seem to make it probable the Wasatch paraffines resulted from such distillations. The absence of any other evidence of heat from the locality makes the presence of the paraffines more noticeable. The question arises, why should here be found the waxy paraffines, while all around so great quantities of asphalt were produced in rocks of nearly if not the same age? Evidently a great amount of work remains to be done before we can scientifically distinguish between the processes which severally resulted in the formation of coal, the oily and buttery paraffines, and the asphalts. While studying the subject a theory of a somewhat speculative nature has occurred to me. Paraffines have been found in the turpentine of pines.* Paraffines are among the most stable of the organic compounds. The hypothesis is suggested whether this waxy paraffine of the Wasatch region may not be due to that contained in the turpentine of conifers, and that this is a residuum of primary decomposition, all that remains of the original turpentine, the more unstable substances having disappeared. It is a fact that in the Rocky Mountain region the coal contains a large quantity of partially mineralized resin.†

Now if resin (dried and oxidized turpentine) has so long resisted decomposition and mineralization, it becomes by no means improbable that if a turpentine contained paraffine, that very refractory substance might remain after all the other ingredients had become decomposed and changed either to coal or to petroleoids, or indeed oxidized to carbonic acid. This question is evidently part of a larger question: how far were the hydro-carbons of the carbonaceous minerals formed within the living organisms from which these minerals were derived?‡

* Watt's Dictionary of Chemistry, III Supplement, art. paraffine. Also Roscoe and Schorlemmer, Chem., vol. iii. pt. 1, p. 140.

† According to Messrs. Remington and Gilson of Salt Lake City there is in Utah a bed of fossil resin several feet in thickness. It is still soluble in most solvents of resin, but will no longer unite with linseed oil to form a tough varnish. I have seen specimens of the mineral but have not made a field examination of the deposit and do not know its geological age.

‡ Mr. G. P. Wall, quoted by Orton, p. 500, gives a graphic picture of vegetable matter partially changed to asphalt. The description appears to refer to cellulose and woody fiber. What would become of the more soluble products of the plant, such as the oils, resins, paraffines and other non-oxygenated hydro-carbons? They appear to be able to withstand decomposition longer than the cellular tissues, and would certainly be dissolved in any petroleoid produced from those tissues. Would they simply enter into solution or into a chemical synthesis? These and other similar questions need to be solved before we can trace the relationships of the coals, petroleums, asphalts, fossil resins and acids, hard paraffines, etc.

Colorado Springs, March 3, 1891.

ART. XIV.—*Photographic Investigation of Solar Prominences and their Spectra;* by GEORGE E. HALE. With Plate VIII.

IT is now many years since any important advance has been made in our knowledge of the solar prominences. With the exception of spectrum photographs made at the Siam and Egyptian eclipses, and the momentary glimpses of mysterious "white prominences" during totality, almost nothing has been added to the collection of facts gathered nearly twenty years ago. After Professor Young's vigorous attack upon the chromosphere and prominence lines at Mount Sherman and elsewhere, other investigators seem to have been impressed with the belief that no further additions could be made to the long catalogue of lines drawn up by our most skillful solar observer, and the spectroscopic side of the matter was allowed to rest, though a continuous record has been kept of the forms of chromosphere and prominences. While it is probably true that the most persistent watching would be required to increase the number of known lines in the visual spectrum, it is rather singular that the importance of photography in a study of the ultra-violet has been entirely overlooked. While the positions of spots on the sun's disc are daily recorded by photography, the same cannot be said of the chromosphere and prominences, and even in investigations of the extremely complicated spot spectra, photography has been but little employed, experiments with it not having proved very successful.

It is unnecessary here to urge the importance of using photographic processes to assist the eye in nearly all classes of solar investigation. What has been said for photography in other fields of astronomical or physical research will apply with equal force in the present instance, and the results of many years speak forcibly for themselves. It is of course very desirable that the ultra-violet should be studied, and for this purpose visual observations are of no service. Again, prominence forms as photographed through different lines should be compared, and the sequel will show that photography affords the only means of investigating the white prominences.*

The history of attempts at solar prominence photography extends over twenty years, and it is remarkable that the earliest experiments were the only ones which gave any indications of possible success. In 1870 Professor C. A. Young made the first prominence photographs taken without an eclipse. Using the hydrogen γ line (G'), and a wide tangential slit, a magnified image of the prominence was formed upon an ordinary

* See also Technology Quarterly, vol. iii, No. 4.

collodion plate, and given an exposure of nearly four minutes.* Professor Young has very kindly shown me silver prints from the best original negatives; in these only the general outline of the prominence can be faintly seen. This is due partly to a small displacement of the image during the exposure, as the polar axis of the telescope was slightly out of adjustment. The nebulous character of G′ makes its use objectionable, but the serious difficulty with this line lies in the employment of a wide slit. The brilliancy of the background of atmospheric spectrum increases very rapidly when the slit is opened, while the prominence itself grows no brighter. Thus the contrast in a photograph is greatly decreased, and the general illumination of the field, due to diffused light from the grating, or fluorescence of the prisms or object glasses, conspires to hide all details of structure. For these reasons the method has never been employed in practice.

It is beyond the scope of the present paper to describe the various methods of prominence photography proposed by Braun in 1872, Lockyer and Seabroke in the same year, Lohse in 1874 and 1880, Zenger in 1879, and Janssen in 1881. Suffice it to say, that in no instance was any success attained sufficient to bring the method into practical use, and in 1889 it was impossible to see where any advance whatever had been made beyond the brief experiments of Professor Young with a simple open slit.

In undertaking an investigation of the subject in the summer of the year last named, the writer devised two methods of accomplishing the desired result with a narrow slit, for it was evident that with any line in the prominence spectrum as then known, the use of a wide slit could not have more than an extremely limited application. In the first method the rate of the driving clock of the equatorial is so changed that the sun's image drifts at right angles across the slit of a spectroscope of high dispersion. At the focus of the observing telescope (of equal focal length with the collimator) a photographic plate moves at the same speed, at right angles to the axis of the telescope, and in the direction of dispersion. A narrow slit just in front of the plate allows only the line in use to fall upon it, and thus prevents fogging. It will be easily seen that fresh portions of the plate will be uncovered as the prominence drifts across the slit, and the result will be a latent image upon the photographic plate.

The second method exactly reverses the operations of the first. The sun's image is held in a fixed position by the driving clock of the equatorial, while the plate at the focus of the observing telescope is also stationary. The slit of the spectroscope is caused to move steadily across the end of the collima-

* Journal Franklin Institute, Oct. 3, 1870.

tor, while a corresponding slit before the plate moves at such a rate that the line in use passes constantly through it.

Both of these methods, together with the experiments carried on with the first at the Harvard Observatory and more recently at the Kenwood Physical Observatory, have been already described,* and in the present paper I wish to consider especially the results obtained in Chicago within the last few weeks.

In my earliest attempts at photographing the prominence spectrum I was much surprised to find narrow, sharp, bright lines running up through the center of the dark shades of both H and K, apparently to the very top of every prominence. At Mount Sherman in 1872 Professor Young, whose eyes are exceptionally sensitive to the shorter wave-lengths, had been able to see similar reversals of H and K, but the difficulties of observation were so great that he considered it probable that the whole width of each dark shade at H and K was reversed, the eye being able to perceive only the maximum of intensity at the center. Once or twice he noticed a bright line estimated to be about one division of Ångström's scale below the central reversal of H, but with the utmost precautions the eye was incapable of any accurate determinations of position or appearance in this part of the spectrum. But with high dispersion and care in manipulation the photographic plate meets with no difficulties, and the lines are obtained with ease. Fig. 1 of Plate VIII shows the reversals photographed with a radial slit, while for the negative used in making fig. 2 the slit was parallel to a tangent at the limb, and about 30″ from it. All of the figures were made directly from the original negatives by a photographic process, and, with the exception of fig. 3, the scale is the same as that at the focus of the spectroscope, the fourth order spectrum of a 14,438 Rowland grating having been employed. Though an excellent one in every other respect the grating gives two orders of ghosts, and the line just below H seems to coincide with one of these; but careful measures of its positions, combined with its appearance as compared with the corresponding first order ghost of K, makes it more than likely that it is an independent line. A set of preliminary measures from two negatives renders it extremely probable that this line is due to hydrogen, as the wave-length agrees remarkably with that obtained by Ames for a hydrogen line at this point (λ3970·25)† but more measures from a number of negatives already in my possession will be needed to settle the question. There seems to be no corresponding line in the solar spectrum, but both the H and K reversals appear

* Technology Quarterly, vol. iii, No. 4, 1890. Astronomische Nachrichten, Nos. 3006 and 3037. Sidereal Messenger, June, 1891. Monthly Notices of the R. A. S., July, 1891.

† Phil. Mag., July, 1890.

to agree in position with narrow dark lines at the center of the dark shades. Above in the ultra-violet the photographs bring out three new lines, which there are good reasons to regard as the first three lines of the hydrogen stellar series, though their wave-lengths have not been determined as yet. The lowest of the three, which probably corresponds with the line called hydrogen *a* in Dr. Huggins's map, has occasionally been glimpsed in the prominence spectrum by Professor Young, and its identity can now be certainly determined for the first time.* But the photographs have also revealed a new and interesting fact. On all the plates made with the focus of the observing telescope accurately adjusted for this region, the first line above K is shown to be a fine, sharp double, the separation of the components amounting to a few tenths of a tenth-metre. A special study of this double will be made when a new photographic object-glass of six feet focus has been completed for the spectroscope. The fourth order spectrum of our concave grating of ten feet radius will also probably be brought into service for work on the solar spectrum in this region.

As already suggested, the two upper prominence lines are probably coincident with two lines in the hydrogen series. Only one of these appears in fig. 2, where it is very faint. A photographic search for the remaining lines of the series is now in progress at the Kenwood Physical Observatory.

The important variations in the relative intensities of prominence lines revealed in eclipse photographs have been partially confirmed by my photographs. So far only one prominence has appeared in which the ultra-violet hydrogen lines could be photographed, and this showed a corresponding increase of brilliancy in the visual spectrum. But the H and K reversals are invariably strong, and easily photographed. Preliminary measures show that both lines probably belong to calcium, but this is yet to be definitely determined, and the origin of the broad dark shades in the solar spectrum is decidedly uncertain. In spite of the constant presence of the H and K bright lines in prominences, it can hardly be supposed that the substance producing them can be ordinary hydrogen, for several reasons. In the first place there is no provision for K in Balmer's series, and H certainly does not fall in the position of the hydrogen line, as it is about 1·5 tenth-metre more refrangible. Again, H and K do not follow the hydrogen lines in their intensity

* Great confusion is likely to result from the indiscriminate use of the letter H for "hydrogen" or for Fraunhofer's H line, and also in applying the Greek letters to the hydrogen lines, for some call the *c* line *a*, and others apply the same letter to the first hydrogen line in the ultra-violet. It is desirable to adopt some common nomenclature, and probably the most natural is to begin with *c*, and call this line "hydrogen *a*," or else refer to each line by its wave-length.

variations, and in several cases I have photographed both H and K expanded and reversed over spots in which the C and F lines showed no signs of reversal. Some very recent photographs suggest the possibility that the substance producing the H and K bright lines occasionally ascends in prominences to a higher level than that reached by hydrogen itself (observed through C) in the same prominences, and the "white prominences" observed and photographed at several eclipses offer a most interesting case in point. At the Grenada eclipse of August 29, 1886, Prof. W. H. Pickering found in his photographs made during totality a spiral prominence 150,000 miles high, which had for the only lines in its spectrum H, K, and a faint trace of an ultra-violet line about half-way between K and L. There was also a brilliant continuous spectrum in the visible region, but as the usual hydrogen lines were absent, Prof. Tacchini was unable to see the prominence by the usual spectroscopic method, either before or after totality. In his report Prof. Pickering adds: "It is highly probable that a great number of prominences pass by entirely unnoticed, because we rely solely upon visual instead of photographic methods of observation."* At the present moment I have not the remaining literature of this subject within reach, and must trust to memory for a few more references to simular phenomena. In the report of the eclipse of Jan. 1, 1889, published by the Lick Observatory, Dr. Swift alludes to the peculiar white appearance of some of the prominences, and in comparing the prominences photographed at the same eclipse with those observed on the same day at Palermo, P. Tacchini notes the presence in the photographs of two prominences seen neither at Palermo or Rome, and concludes that they are white prominences, similar to the great white prominence shown in the Grenada photographs.† Capt. Abney's photographs of the prominence spectrum at the Egyptian eclipse, and a suspicion of Trouvelot's (given in the Comptes Rendus) that a certain floating prominence must have some invisible connection with the chromosphere, make evident the extreme desirability of some means of photographing both visible and invisible prominences in full sunshine. The various theories connecting sun-spots and prominences are based upon observations in the visual region, and the invisible prominences, which are shown by the Grenada photographs, to reach at times to great elevations, have been left entirely out of account. It will be seen shortly that this need no longer be the case, and we may hope soon to have a daily record of all classes of prominences, both visible and invisible.

* Annals of Harvard College Observatory, vol. xviii, No. V, p. 99.
† Atti della R. Accad., dei Lincei, 1889.

When the sharp and brilliant reversals of H and K were discovered at the beginning of my investigations in prominence photography at the Kenwood Physical Observatory, it at once became evident that a considerable advance had been made, for the substitution of either of these lines for the less refrangible hydrogen lines removed the serious difficulty of photographing the longer waves of the C region with short exposure. But apart from their position in the spectrum, the distinctive peculiarity of H and K specially fits them for prominence photography. The narrow bright lines, instead of being superposed on a brilliant continuous spectrum, as is the case with all of the other prominence lines, lie in the center of broad, dark bands, where the troublesome light of the atmosphere is missing. Thus both slits used in my apparatus for photographing the prominences could be much more widely opened, without the difficulty of fogging and loss of contrast experienced with the other lines. The result was that the first photograph made in this way proved a success. The prominence drifted slowly across a narrow tangential slit, and behind the second slit, at the focus of the observing telescope, a small cylinder with its axis parallel to the slit, carried a strip of sensitive film at a speed equal to that of the moving solar image. A smooth and uniform motion of the cylinder was produced by a small clepsydra. The photograph showed the form of the prominence very well, and with considerable contrast. It was then concluded, on account of the great width of the dark shades at H and K, that for prominences of not too great size (the image of the sun on the slit plate is two inches in diameter) it would only be necessary to use a wide slit, and give a short exposure. Fig. 3 shows the result of such an experiment. The wide slit was nearly tangent to the sun's limb, but did not quite touch it, in order to exclude the direct light. The exposure was about 2 seconds, and the dispersion that of the fourth order of a 14,438 grating. As an object-glass ($3\frac{1}{4}$ inches aperture and $42\frac{1}{2}$ inches focus) corrected for the visual region was used in the observing telescope of the spectroscope, the foci for H and K are slightly different. The photograph is about twice the size of the original, and was enlarged directly from it in the camera.

Although this method will serve to photograph the invisible prominences it is evident that there are two objections to it. In the first place it would be very troublesome to find invisible prominences, and to do so it would be necessary to take a large number of photographs with the slit tangent at various points on the limb. This could be remedied by using a curved or ring slit. Again, prominences surpassing a certain size could not be photographed, though for single narrow prominences

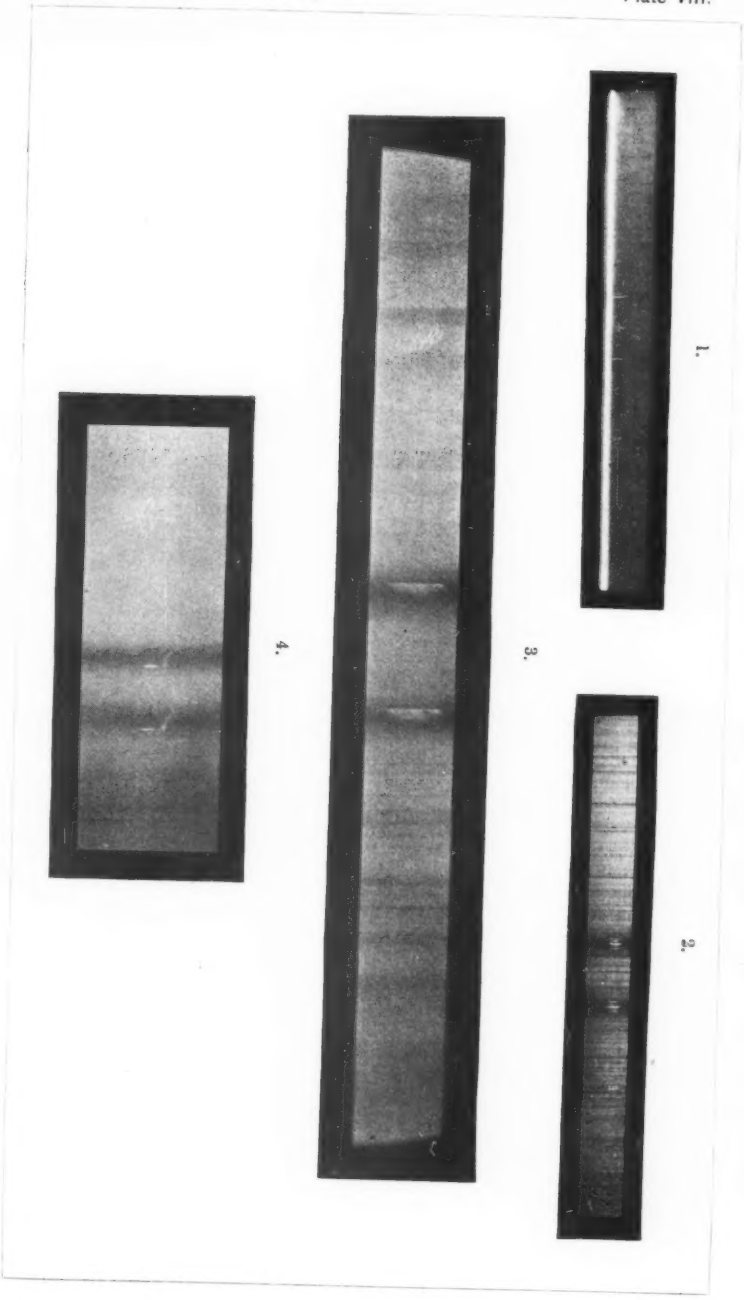
reaching to a considerable elevation it would be desirable to make the direction of the slit coincide with the direction of the longest axis of the prominence, the direct light from the limb being excluded by a small strip of metal, sliding under the slit. To overcome all of these difficulties I have devised a new form of apparatus, which will much excel the rotating cylinder in ease of adjustment, and allow the use of ordinary glass plates, instead of the celluloid film, which decomposes if kept for any length of time. A new form of clepsydra, of much larger size and with an improved valve, will replace the smaller one before used. The equatorial is also to be supplied with a 12 inch photographic object glass, and a new tube parallel to the old one, so that by a suitable form of cell, either object glass may readily be used on either tube, as the spectroscope is too large and heavy to be easily moved. The instrument will also allow eye observations through the C line to be made at the same instant that a photograph is exposed through H and K, and this will be important in comparisons of the form and extent of prominences as observed through different lines.

Since the above article was put in type, it has been decided to add another illustration (figure 4), which shows a much larger prominence, and of such peculiar shade as to be particularly interesting. The following is the record made on the observatory journal: "Chicago, July 8, 1891, 23 hours 45 minutes, prominence through H and K. As at first seen prominence was low, changed rapidly. A great flame shot out of the center about 80,000 miles high and lasted about fifteen minutes when it resumed its first shape." As shown in the figure, a low portion of the prominence is seen near the limb of the sun. This was what was first observed. The high portion lasted only about fifteen minutes and then the prominence returned to its original form as shown on the low portion of the negative.

Brooklyn, July 6, 1891.

Art. XV.—*A Gold-bearing Hot Spring Deposit;* by Walter Harvey Weed.

A few months ago, a suite of specimens from the Mount Morgan gold mine, of Queensland, Australia, was received by the writer from Dr. R. L. Jack, the government geologist of Queensland, accompanied by the request that they might be examined and compared with the siliceous sinters from the hot spring region of the Yellowstone Park. These specimens possess unusual interest, since Dr. Jack's observations show that this remarkable mine, which paid a dividend of £1,200,000 sterling, in 1889, is the deposit of a hot spring, the ore being a siliceous sinter impregnated with auriferous hematite. The structure of this ore-body, as developed by the working of the



mine, and a microscopical and chemical examination of the sinter, both confirm this hypothesis. It is therefore necessary to add this form of deposit to those already recognized in the classification of ore bodies.

As but little is generally known of the Mount Morgan mine a few notes condensed from Dr. Jack's report* are inserted:

This remarkable ore deposit forms the upper portion of the hill known as Mount Morgan, whose summit is about 500 feet above the surrounding lowland, and is some 1200 feet above sea level. The rocks in the immediate vicinity of the mine are bluish-gray quartzites forming part of a much disturbed series of beds of Carbonifero-Permian age. These beds are intersected by numerous dikes of igneous rocks, mainly rhyolite, and intrusive bodies of diorite and other eruptives. Reefs of gold-bearing quartz are common in this area of metamorphic rocks.

The workings of the mine show that the siliceous sinter forms a surface covering upon the slopes of the "mount." In such situations it has been found to be usually without gold, but the cup-shaped mass of sinter forming the central core and summit of the hill is impregnated with brown ironstone carrying as high as 169·86 oz. of gold to the ton.

The tunnels driven through the ore body at various levels show that the sinter though generally an unbroken mass is sometimes formed of large angular blocks, as if the deposit had been shattered. A dike of igneous rock now thoroughly decomposed and kaolinized, cuts the quartzites and extends upward through the sinter. There is no hydrothermal activity whatever, in the vicinity of the mine, at the present day, though hot springs occur in other parts of Queensland.

The sinter which Dr. Jack has sent as representative of that forming the main body of the ore deposit he describes as "a very light, frothy, spongy or cellular rock, so light from the entanglement of air in its pores as to float in water like pumice." In thin section this material is dark between crossed nicol prisms; its structure and general appearance is that of a hot spring deposit, though no sinters quite like it have as yet been found by the writer. It can be positively stated that this material is not a pumice, but is a hot spring deposit. The analysis No. 1 of the following table was made in the Laboratory of the U. S. Geological Survey by Mr. E. A. Schneider, shows this sinter to be a remarkably pure form of opal.

Analysis No. II, of a sinter from the Yellowstone Park, was made by J. E. Whitfield in the laboratory of the U. S. Geological

* Mount Morgan Gold Deposits. Second Report by Robert L. Jack, Government Geologist, Queensland, Australia, 1889.

Survey, and No. III. from Steamboat Springs, Nevada (Woodward).*

A specimen of the auriferous hematite from this mine possesses a stalactitic structure, and must have formed in a cavernous space in the sinter. Similar siliceous ironstones are formed about the hot springs of the Yellowstone, by the oxidation of the cooled overflow waters of the springs as they drip into cavities and holes in the sinter deposits.

Analysis of Siliceous Sinter.

	I.	II.	III.
Silica	94·02	93·88	92·67
Alumina	2·27	1·72	0·80
Ferrous oxide		0·14	
Lime	0·07	0·25	0·14
Magnesia	trace	0·07	0·05
Soda	----	0·28	0·18
Potash	----	0·23	0·75
Sulph. acid	----	0·20	----
Chlorine	----	----	----
Sodic chloride	----	0·18	----
Water (105°)	1·07	3·37	5·45
Ignition	2·29		
Total	99·72	100·33	100·04

Two peculiar specimens of the earthy portions of the ore-mass are thus described by Dr. Jack in a letter to the writer. "It occurs surrounded by siliceous sinter on the southern slope of the mountain 35 feet perpendicularly beneath the surface, and 39 feet from the mouth of the tunnel on No. 3 bench. The rock is full of tortuous anastomosing glazed pipes resembling worm borings," and has throughout a sort of volitic structure. In thin section the rock is seen to be composed largely of feldspathic material and opaline silica, showing occasional crystal grains. In the hand-specimen the rock appears to be formed of an aggregation of pellets averaging a millimeter in diameter. These pellets possess a compact outer envelope, about a more open cavernous center, and are formed entirely of white opaline silica. Grains of white decomposed rock, a leached eruptive, with occasional grains of quartz are also common. The network of channels, and concretionary pellets, which characterize this rock, is a not uncommon structure of the calcareous deposits of the Yellowstone Park, and is due to the ascent of gas bubbles, through the soft mass. Siliceous sinters have also been found, possessing a honeycombed structure of

* Reports of 40th Par. Survey, vol. ii, p. 826.

this nature, about the springs on the northern shores of the Yellowstone Lake.

It has long been known, that the Steamboat Springs of Nevada, are surrounded by deposits of sinter in the fissures of which ore deposition is now taking place, a small amount of gold being found in these contemporaneous mineral veins.* The Mount Morgan mine is, however, the only hot spring deposit known, that has been found to contain gold in commercially valuable quantities.

The most remarkable hot spring district of the world is undoubtedly that of the Yellowstone Park. The variety of these springs, and the extensive deposits which they have formed, naturally suggests the possible existence of metalliferous deposits. Yet a careful search for such deposits has been made for the past eight years, by the members of the geological survey party, under Mr. Arnold Hague, without bringing to light a single case of this sort. Extensive collections of the hot spring waters and of the hot spring deposits have been subjected to most careful analytical examinations in the laboratory of the Survey, without finding even a trace of the precious metals.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Chemistry of the Secondary Battery.*—The phenomena of charging and discharging a secondary cell are accompanied by chemical changes in the electrodes and in the electrolyte, attended with an evolution of gas. These phenomena have been investigated by Cantor for the purpose of ascertaining what these chemical changes are; the electrodes and the electrolyte both being analyzed before and after charging and the oxygen and hydrogen given off during the process measured. Some difficulty was found in ascertaining directly the changes in the electrodes; so that they were indirectly determined by charging each plate of the cell separately, using as a second electrode, a plate whose chemical constitution remains unaffected. Under these conditions any change which takes place in the electrolyte must be due solely to the reaction taking place between it and the electrode, including the gas evolved. Since this gas can be determined and also the change which has taken place in the composition of the electrolyte, it is evident that from these data the change taking place in the electrode itself can be ascertained. The author's studies thus far have been confined to the negative plate, this plate consisting of a sheet of lead coated with a mixture

* Becker, Geology of the Quicksilver deposits, page 343.

of lead oxide and lead sulphate. This plate is made to form the cathode and a plate of platinum the anode in a solution of sulphuric acid. The following are the results obtained: The first action on the plates is to convert the lead oxide into sulphate. Then the hydrogen evolved in the electrolysis reduces this lead sulphate forming metallic lead and sulphuric acid. The metallic lead thus freshly reduced attacks the sulphuric acid, evolving hydrogen and forming lead sulphate again; these reciprocal processes continuing until a condition of equilibrium is reached and the cell is charged. This local action it is which has led Streintz and others erroneously to conclude that hydrogen is occluded in the lead plate.—*Monatsb.* ix, 433; *J. Chem. Soc.*, lx, 514, May, 1891. G. F. B.

2. *On the Dead Space in Chemical Reactions.*—A third paper has been published by LIEBREICH on the dead space in chemical reactions. The appearance of this dead space depends in the view of the author upon the less mobility of the molecules at the surfaces of liquids; a fact which he seems to have proved by a series of interesting experiments. From this it follows that the surfaces of liquids oppose resistance to the motion of solid bodies against them, when driven by a slight force, in the same way as a solid wall would do. Such phenomena may be produced when one liquid is allowed to rise through another of less density, in case the friction-coefficient of the liquids is sufficiently large. The author abundantly shows how by the application of different meniscus-shaped forms, the shape of the entering liquid currents suffers changes; while in a certain sense it adapts itself to them. In this way phenomena can be obtained quite analogous to those which are observed in the dead space in chemical reactions.—*Ber. Ak. Berl.*, 1890, 1239; *Ber. Berl. Chem. Ges.*, xxiv, (Ref.) 301, April, 1891. G. F. B.

3. *A new Reaction of Carbon monoxide.*—BERTHELOT has observed that a solution of silver nitrate, to which has been added just enough ammonia to redissolve the precipitate at first formed, becomes colored brown when a current of carbon monoxide is passed through it or when an aqueous solution of the gas is added to it, even in the cold. On heating it becomes darker and a precipitate is thrown down.—*C. R.*, cxii, 597; *Ber. Berl. Chem. Ges.*, xxiv, (Ref.) 348, May, 1891. G. F. B.

II. GEOLOGY.

1. *On the Relations of the Eastern Sandstone of Keweenaw Point to the Lower Silurian Limestone;* by M. E. WADSWORTH. (Communicated).—One of the assistants (Mr. W. L. Honnold) of the Michigan Geological Survey, has been engaged in the study of the relations of the limestone west of L'anse to the Eastern or supposed Potsdam Sandstone of the Copper-bearing range. This locality is described in Jackson's Report, 1849, pp. 399–452, Foster and Whitney's Report Part I, 1850, pp. 117–119, and in

Rominger's Report, 1873, 1, part III, pp. 69–71; and the limestone considered from its fossils to be Trenton or some adjacent Lower Silurian strata. It was inferred by Jackson that the limestone underlies the sandstone but by the other observers that it overlies it although no direct contact was seen.

Excavations made by Mr. Honnold's party, and reported by him, have developed the contact of the two formations, and show that the two form a synclinal or oblong basin-shaped fold, with the limestone overlying, and in direct contact with the sandstone. The existence of this fold in the sandstone as well as in the limestone removes the difficulty previous observers have had in reconciling the obviously tilted limestone with the supposed horizontal sandstone, and proves that the Eastern sandstone exposed here is of Lower Silurian age and older than this limestone.

At the point of contact of the two formations, exposed by excavation, the sandstone and limestone appear to be comformable, and they are seen to constantly agree in dip and strike. The contact between the two formations is abrupt, without any beds of passage, although the upper layers of the sandstone contain considerable carbonate of lime and magnesia, and the lower layers of the limestone much silica.

These observations are considered to be confirmatory of the commonly received view of the Potsdam age of the Eastern Sandstone; while the contorted state of the sandstone, extending at least one and one-half miles west from the limestone locality, may have weight in deciding the relative age of the Eastern sandstone and the Copper-bearing rocks.

A careful study of the fossils will be made and additional field work done, when the results will be published in detail.

Michigan Mining School,
Houghton, Michigan, July 3d, 1891.

2. *Expedition to Mt. St. Elias in the summer of* 1890 *by Israel C. Russell.* 200 pp. 8vo, with 20 plates and several figures. —The third volume of the National Geographic Magazine contains an account of this expedition to Mt. St. Elias by Mr. Russell. It went out under the auspices of the National Geographic Society and the United States Geological Survey. Mr. Mark B. Kerr was the topographical assistant in the survey, and Mr. E. S. Hosmer of Washington, a volunteer general assistant. Although the summit of Mt. St. Elias was not reached, important additions were made by it to the knowledge of the glaciers of the region and highly interesting discoveries regarding its geology. The formations recognized are (1) sandstones and shales about Yakutat Bay, and westward to Icy Bay, which Mr. Russell names the *Yakutat system;* (2) shales, conglomerates, limestones, sandstones, etc., named the *Pinnacle system*, occurring in the cliffs of Pinnacle Pass, 5000 feet above the sea-level, and along the northern and western borders of the Samovar Hills on the borders of the Seward glacier; and (3) the metamorphic schists of the main

St. Elias range. The limestone of the second of these formations was found to be fossiliferous, and to afford a Pecten, *Mya arenaria*, *Mytilus edulis*, *Leda fossa*, *Macoma inconspicua*, *Cardium Islandicum*, *Litorina Atkana*—species that are now living, according to Dall, in the cold waters of the region. The age of the beds, is therefore, as stated, "Pliocene or early Pleistocene." The Yakutat beds are regarded as probably younger than those of the Pinnacle system.

The uplifts of the region producing the mountains, including St. Elias, are consequently referred to an epoch since "the close of the Tertiary." In the view of Mr. Russell "the southern face of Mt. St. Elias is a fault-scarp. The mountain itself is formed by the upturned edge of a faulted block in which the stratification is inclined northeastward. The mountain stands at the intersection of two lines of displacement, one trending in a northeasterly and the other in a northwesterly direction. The one trending northwestward extends beyond the junction with the northeasterly fault. The point of union is at the pass between Mt. St. Elias and Mt. Newton. The upturned block, bounded on the southwest by a great fault, projects beyond the northeasterly fault. It is this projecting end of a roof-like block that forms Mt. St. Elias."

This view of the mountain is before the future investigator. Another view, for like study, is the possibility that St. Elias existed in essentially its present form before the Quaternary, and had (along with the country about it) 5000 or more feet added to its elevation above the water-level at the time of the uplift of the Quaternary beds.

3. *Glacier scratches south of the "terminal Moraine" in Western Pennsylvania.*—Messrs. P. M. Foshay and R. R. Hice, in a paper in the 2d volume of the Bulletin of the Geological Society of America (p. 467), describe and figure glacial scratches observed by them on the western bluff of the rock gorge of the Beaver, near the mouth of the Connoquenessig, "two miles or more south" of the "terminal moraine" as located by Lewis and Wright. Some of the grooves are 5 feet wide and 18 inches deep. The authors remark that the grooves may be within "the fringe" of scattered erratics south of the line of the moraine, described by Lewis, but observe that they are as much glacier-made as those of Kelly Island in Lake Erie. For an article by Mr. Foshay on the pot-holes and pre-Glacial drainage of the same region, with a map, see vol. xl of this Journal, p. 397, 1890.

4. *Losses of Cape Cod by sea-encroachment.*—In the U. S. Coast and Geodetic Report for 1889, H. L. Marindin, Assistant, gives details with regard to the losses of Cape Cod. In the southern section, 6 miles long, the crest-line of the beach has receded in 19 years at the rate of 8 feet a year. In a middle section of 4 miles, the shore-line has receded 8 feet in 31 years. In the northern section of 14 miles (from the Nausett Three Lights to the Highland Light in Truro) the mean recession is 3·2 feet per year; and it indicates a removal in 40 years of 30,231,-

038 cubic yards, or 755,756 cubic yards per year, or 53,784 cubic yards per linear mile. The total loss from the three sections is stated at 32,233,030 cubic yards.

5. *Der Peloponnes Versuch einer Landeskunde auf geologischer Grundlage*, nach Ergebwissen eigener Reisen von Dr. ALFRED PHILIPPSON. 8vo. Berlin, 1891. (R. Friedländer and Son.) Part I of this work on the Geology of the Peloponnesus, extending to 272 pages, is accompanied by a large, colored geological map and many profile sections.

III. BOTANY.

1. *Botanic Gardens in the Equatorial Belt and in the South Seas* [*First Paper.*]—It it my purpose to give, in the following notes, some account of the more important Botanic Gardens visited by me during a recent journey. The tour carried me from Genoa, through the canal at Suez, to Ceylon, in which country Pérádeniya and Hakgala were examined; thence to Adelaide in South Australia; Melbourne and Geelong in Victoria; Hobart in Tasmania; Dunedin, Christchurch, and Wellington, in New Zealand; Sydney in New South Wales; Brisbane in Queensland; Buitenzorg in Java; Singapore in the Straits Settlement; Saigon, Hong Kong, and Shanghai, in China; and Tokio in Japan. With the exception of Shanghai and Tokio the visits were made at favorable seasons: in northern China and in Japan the spring was not far advanced, but the early flowers were in perfection.

The journey was undertaken with a view of securing from the establishments in question for the University Museum at Cambridge, specimens illustrative of the useful products of the vegetable kingdom. In every instance, the writer met with a cordial reception and received innumerable courtesies, for which he desires to thank again the Directors, Curators, and Superintendents of the various botanical establishments. Every facility was afforded for careful inspection of the workings of the Gardens and Museums, and it should be added, of the educational institutions with which some of them were connected.

A satisfactory photographic outfit rendered it possible to supplement the collections of photographic views which were purchasable at most points; so that the series, now stored in the Museum at Cambridge, may be regarded as one of the largest yet brought together. It comprises views not only of groups of plants both in gardens and in their wild state, but of individual plants as well. Early next year these illustrations will be accessible to visiting naturalists.

The present sketch will follow essentially the route outlined in a preceding paragraph, beginning with the gardens in Ceylon.

Pérádeniya and Hakgala. (*Ceylon*).—After the deserts of Egypt and Arabia, and of treeless Aden have been passed, the traveller comes by an abrupt transition upon tropical luxuriance of vegetation. There is to be sure, a distant glimpse of Socotra,

but its shores are too far away to yield anything plainly discernible, and even Minicoy, an island lying between the Maldives and Laccadives, gives only a faint suggestion of plant life. Its low-lying land is fringed with scattered coconut palms, of which later one sees so many. Before reaching Ceylon the ship passes within sight of the southern point of India, but not near enough to show what its plants are like. In fact, therefore, the arrival in the harbor of Colombo brings a surprise. Coming down to the shore, and extending as far as the eye can reach on either side, are crooked coconut palms, here and there intermingled with trees having foliage of the deepest green. A botanist is struck at once by the superb capabilities of such a country for a tropical garden. These capabilities were not overlooked by the Dutch, who succeeded the Portuguese in possession. A Botanic Garden was founded by them at Slave Island in Colombo, but when the Dutch were driven out by the British it fell into neglect. There was, however, at this period, an excellent garden connected with the country place of the first English Governor, near Colombo, which at the begining of this century was under the charge of a naturalist, who gave it somewhat the character of a botanical garden.

In 1810, Sir Joseph Banks sketched the plan for a Botanical Garden in Slave Island, Colombo, and succeeded in transferring thither from Canton, Mr. Kerr, who became its chief. According to the work from which I have derived these facts, the Slave Island garden was found subject to floods, and consequently the establishment was moved to Kalutara. One finds here and there in Colombo traces of the old occupancy remaining in the names of some of the streets, "Kew" for instance. From Kalutara the garden was transferred in 1821 to its present site. Since that time the large garden has established four branches, in order to secure all the advantages which can come from having land at different altitudes and with different exposures.

The branch gardens are (1) *Badulla*, founded in 1886, in the eastern part of the island, with an elevation somewhat over 2,000 feet. "The climate here is somewhat drier than on the western side of the hill region, receiving but little rain with the south-west monsoon." (2) *Anurâdhapura*, dating from 1883, about a hundred miles north of the large garden, at the ancient capital of the island. Besides the interesting ruins at this point which are well worth seeing, there exists the oldest historical tree in the world, *Ficus religiosa*, (the sacred Bo), assigned to 288 B. C. This garden has a short rainy season, and a hot dry climate. (3) *Heneratgoda*, 33 feet above the sea, and thoroughly tropical, is on the railroad running from Colombo to Kandy. It was founded in 1876. Here certain plants which cannot be grown at Péradeniya are very successfully cultivated. (4) *Hakgala*, established in 1860, as a nursery for Cinchona cultivation, is near Nuwara-Eliya, (commonly pronounced "Newralia") the famous sanitarium. It is almost 6,000 feet above sea-level, in a place of sur-

passing beauty. Above the garden is a frowning double cliff 1,500 ft. high, and all around, the views are most attractive. The Gate affords one of the best of these. The landscape reaches over the Uva district towards the Haputale gap and the Madulsima hills. On entering the garden the bewilderment begins. On every hand one sees species in the most grotesque juxtaposition. Plants from Australia such as Casuarinas and Acacias are perfectly at home with East and West Indian, Japanese, and English plants. Of the latter there are many which seemed thrifty and well established.

Although the garden is used primarily for experimental purposes it has been laid out with regard to effectiveness of grouping and with remarkable success. A botanical visitor is, however, constantly trying to separate in his mind the different plants from the curious collocations which everywhere abound and demonstrate better than in any other place I have ever seen, the wide range of tolerance of climate. The superintendent, Mr. W. Nock, who has had large experience in the West Indies, has carried on some interesting experiments in acclimatizing plants from the western hemisphere, such as "cherimoyer" and the like. There are few plants in the garden more attractive from an economic point of view than the vegetables of doubtful promise, such as Arracacha, and those of assured culinary position "Choco" or "Chocho" (*Sechium edule*) for example. Some of the medicinal plants in hand were doing well in every way, while others have proved somewhat disappointing, for instance, jalap and ipecacuanha.

The ferns, especially the tree ferns, and the species of Eucalyptus form one of the marked successes at this garden. Mr. Nock stated that the most troublesome weed in the garden is a species, (perhaps more than a single species) of *Oxalis:* it is simply impossible to eradicate it.

(5) *Péradeniya.*—The gardens are four miles from Kandy, and about eighty from Colombo. The railroad passes through lowlands and rice-fields, past native villages surrounded by plantains and coconuts, and through occasional jungles, until it reaches higher ground. The scenery changes rapidly, forests now and then appearing in the foreground, with occasional views of distant castellated mountains. As the mountains rise out of the terraced rice-fields and from the shrubs of the jungles, the eye catches on every hand glimpses of groups of bent coconut palms and straight arecas. It is difficult to realize that these palms mean, perhaps without exception, human habitations at their feet. Through these scenes of enchanting beauty, the railroad has made its way, demanding here and there very skillful engineering. The track is lined with *Lantana* which is slowly giving way before the encroachments of a still stronger invader, a Composite from Mexico. *Mimosa pudica* is also widely spread as a strong weed.

The drive from Kandy to the great garden is through a well shaded street lined with native houses. These are gathered at short intervals into villages.

My first visits to this garden were made, as were those in every other instance save one on the whole tour, without reporting to the Director. In this way a student can take things very leisurely, and look up matters of detail which it is not right or courteous to trouble the chiefs with : later, all special points of interest which have escaped notice are likely to be brought out by a walk with the Director. The establishment at Pérádeniya consists (1) of 150 acres of garden proper and of arboretum, (2) of a museum and herbarium with library attached. The Director, Dr. Henry Trimen, widely known as an author and editor, controls not only these, but the branch gardens as well, making his headquarters at Pérádeniya.

Once for all it may be said that botanists are made welcome in every way, finding every facility for carrying on systematic work. The climate is healthful, provided one takes ordinary and reasonable precautions against exposure to the direct rays of the sun in the hottest part of the day. If I remember rightly, the Director. even in his long walks through the garden and in his excursions seldom wears the conventional pith-helmet. American students need not fear that they will suffer greater discomfort from the hot weather at Kandy and Pérádeniya than in summer in the United States and Canada. Access to Ceylon (and for that matter, Java) has now been made so easy by the newer swift steamers, that it seems advisable to mention these facts about the climate.

It is impossible to describe the wealth of material placed at the service of every visitor to the two great gardens of the equatorial belt, that under present review and the one at Buitenzorg, to be considered in a subsequent note. It is equally impossible to institute a comparison between the two.

In both of these vast establishments the student finds magnificent specimens of all or very nearly all the useful plants belonging to hot moist climates. Many years ago the writer had the privilege of seeing tropical plants at the Isthmus of Panama, but even the delightful impressions received on that occasion, which had perhaps become deepened with the lapse of time, were forgotten in the presence of the abounding luxuriance of these palms, bamboos, glossy-leaved evergreens, and tangled climbers.

At Pérádeniya the most characteristic plants are so placed as to be seen to good advantage. This was frequently observed when in search of points of view for photographing individual specimens. Moreover, the system of labelling is about perfect. Dr. Trimen makes use of a large staff formed out of baked clay, shaped so as to give an inclined surface on which the name is plainly painted. These brick-red labels with their painted disk are not unattractive ; at any rate, they do not detract from the general effect of the broad lawns bordered by gigantic trees.

The most remarkable single tree in the garden is the Seychelle Palm or double coconut, now almost fifty years old. The giant and other bamboos, the grove of India-rubber trees near the

main entrance, and the avenue of Oreodoxa, are only a few examples of the finer groups of single species. The most imposing group of different species is that of the palms not far from the gate. The classified arboretum is rich in fine specimens, the principal orders being represented on a generous scale.

The nurseries, kitchen-garden, rockery for succulents, ferneries, and clusters of economic plants are on a scale commensurate with the arboretum. As might be expected, the orchids are by no means so fine as the collections one sees in large private establishments in England and on the continent: it is not possible to command the conditions of growth for all the finer species with the same degree of certainty as in colder regions where a stove means something.

At the time of my visit, *Amherstia nobilis* and the great crape myrtle were in full flower, and a large Talipot palm in bloom was one of the most conspicuous objects. I was a little too early in Ceylon for some of the tropical fruits, and too late for a few others, but fortunately was able to remedy this lack farther on in Queensland and Java.

Among the finest of the photographic views of the gardens in Pérádeniya are the following: (1) the main entrance, with the long lines of Assam rubber trees, and the cluster of different palms, (2) the avenue of royal palms, (3) the different bamboos at the ponds, (4) the distant view of the satin-wood bridge. The view from the Herbarium is also one of great beauty.

Visitors to the gardens are greatly assisted by the intelligent native servants detailed to act as guides. They have a fair knowledge of the whereabouts of almost all the important plants and seldom go wrong with regard to names. It should be stated also that the natives employed in widely different stations in the establishment prove, according to the Director and the Superintendent, generally efficient.

The Herbarium is rich in certain directions and can be consulted by students under proper restrictions. The Museum is as yet small.

It remains to be said that plants and seeds are for sale at the garden, at moderate prices. A Wardian case packed with forty assorted plants is shipped for 40 rupees, say about 16 to 20 dollars.

The influence for good which has been exerted in Ceylon by the garden and its branches is incalculable. The establishment has proved a center of scientific activity and of high economic value. G. L. G.

IV. Miscellaneous Scientific Intelligence.

1. *Die Denudation in der Wüste und ihre geologische Bedeutung. Untersuchungen über die Bildung der Sedimente in den Ägyptischen Wüsten;* Johannes Walther, A. O. Prof. Univ. Jena. pp. 224, large 8vo, with 8 plates and 99 cuts. Leipzig, 1891. (S. Hirzel.)—This memoir makes part of vol. xvi of the

Transactions of the Mathematico-Physical Section of the "Königl. Sächsischen Gesellschaft der Wissenschaften." It is a work of great interest, treating of the causes producing denudation in the Egyptian desert and its results, and is illustrated by many excellent and instructive figures. The chief causes of denudation mentioned are deflation, or the work of the winds directly in denudation by removing whatever is sufficiently loose or has been loosened by decomposition or otherwise, and the work in abrasion by transported sands; 2d, Insolation, or the effects of the sun or heat over the surface of rocks by changes of temperature and especially those of day and night; (3) Decomposition or alteration through any means; (4) The eroding and transporting action of waters, rains being not wholly absent. (5) Vegetation, as a means of modifying results. The results in the formation of deposits are also described. The work is of special value to American geologists.

2. *History of Volcanic Action in the area of the British Isles*, by A. Geikie. Anniversary Address before the Geological Society of London, Feb., 1891. Quart. J. G. Soc. xlvii.—More has thus been learned about volcanic action in Paleozoic time from the British Isles than from all the rest of the world. Dr. Geikie, in his Anniversary Address, commences a full review of the interesting subject. Although extending to one hundred pages, the review covers only the earlier part of the history, to the close of the Upper Silurian.

3. *Magnetic Declination in the United States for the Epoch of* 1890.—Mr. Charles A. Schott has a paper of seventy-five pages on this subject, in the Report of the Superintendent of the Coast Survey, Prof. T. C. Mendenhall, for 1889, consisting chiefly of tables giving the results of observations reduced to the year 1890.

4. *Telescopic Work for Starlight Evenings*, by William F. Denning, F.R.A.S. 361 pp. 8vo. London, 1891 (Taylor & Francis).—There is a peculiar interest and fascination connected with the subject of Astronomy, which even the comparatively uneducated reader cannot but feel, and hence there exists here a field for popular presentation which is hardly equalled in any other branch of science. The present work is one of this class and is fresh in matter, attractive and popular in style and with its numerous illustrations cannot fail to bring pleasure and instruction to all who use it.

5. *Ostwald's Klassiker der Exacten Wissenschaften.* (Wm. Engelmann, Leipzig). Recent issues of this valuable series include:

No. 21, 23. Ueber die Wanderung der Ionen während der Electrolyse. Abhandlungen von W. Hittorf (1853–1859).

No. 22. Untersuchungen über das Radikal der Benzoesäure von Woehler und Liebig (1832).

No. 24. Unterredungen and Mathematische Demonstrationen über zwei neue Wissenszweige, die Mechanik und die Fallgesetze betreffend, von Galileo Galilei. Dritter und vierter Tag (1638).

APPENDIX.

Art. XVI.—*Restoration of Stegosaurus;* by O. C. Marsh. (With Plate IX.)

In this Journal, in 1877, the writer described a remarkable extinct reptile from Colorado, under the name *Stegosaurus armatus*,* and later a much more perfect specimen of another species, *Stegosaurus ungulatus*, from essentially the same horizon, in the Jurassic of Wyoming.† The latter specimen was in fine preservation, and the more important parts of the skull and skeleton, and especially of the remarkable dermal armor, were secured. Subsequently, more than twenty other specimens of these and other species were obtained, so that nearly every part of the osseous structure thus became known, and only portions of the dermal armor were in doubt. A fortunate discovery cleared away most of the doubt in regard to one species, *Stegosaurus stenops*, as the type specimen had the skull, skeleton, and dermal armor together when entombed, and almost in the position they were when the animal died.

With this rich material at hand, an attempt has been made to give a restoration of one of the group, and the type specimen of *Stegosaurus ungulatus* has been selected as the basis. This has been supplemented by a few portions of the skeleton of *Stegosaurus duplex*, apparently a closely allied species from nearly the same locality, while some other parts, especially of the dermal armor, have been placed in accordance with their known position in *Stegosaurus stenops*.

The result is given in Plate IX, which is believed to represent faithfully the main features of this remarkable reptile, as far as the skeleton and principal parts of the dermal armor are concerned. This figure, one-thirtieth natural size, is reduced from a larger restoration, one-tenth natural size, made for

* This Journal, III, vol. xiv, p. 513, December, 1877.

† Ibid., vol. xviii, p. 504, December, 1879. See also, vol. xix, p. 253, March, 1880; vol. xxi, p. 167, February, 1881; and vol. xxxiv, p. 413, November, 1887.

a lithographic plate to accompany the monograph of the *Stegosauria*, prepared by the writer for the U. S. Geological Survey.

In this restoration, the animal is represented as walking, and the position is adapted to that motion. The head and neck, the massive fore limbs, and, in fact, the whole skeleton, indicate slow locomotion on all four feet. The longer hind limbs and the powerful tail show, however, that the animal could thus support itself, as on a tripod, and this position must have been easily assumed in consequence of the massive hind quarters.

In the restoration as here presented, the dermal armor is the most striking feature, but the skeleton is almost as remarkable, and its high specialization was evidently acquired gradually as the armor itself was developed. Without the latter, many points in the skeleton would be inexplicable, and there are still a number that need explanation.

The small, elongated head was covered in front by a horny beak. The teeth are confined to the maxillary and dentary bones, and are not visible in the figure here given. They are quite small, with compressed, fluted crowns, and indicate that the food of this animal was soft, succulent vegetation. The vertebræ are solid, and the articular faces of the centra are bi-concave or nearly flat. The ribs of the trunk are massive, and placed high above the centra, the tubercle alone being supported on the elevated diapophysis. The neural spines, especially those of the sacrum and anterior caudals, have their summits expanded to aid in supporting the massive dermal armor above them. The limb bones are solid, and this is true of every other part of the skeleton. The feet were short and massive, and the terminal phalanges of the functional toes were covered by strong hoofs. There were five well-developed digits in the fore foot, and only three in the hind foot, the first toe being rudimentary, and the fifth entirely wanting.

In life, the animal was protected by a powerful dermal armor, which served both for defense and offense. The throat was covered by a thick skin in which were imbedded a large number of rounded ossicles, as shown in the figure. The gular portion represented was found beneath the skull, so that its position in life may be regarded as definitely settled. The series of vertical plates which extended above the neck, along the back, and over two-thirds of the tail, is a most remarkable feature, which could not have been anticipated, and would hardly have been credited had not the plates themselves been found in position. The four pairs of massive spines characteristic of the present species, which were situated above the lower third of the tail, are apparently the only part of this

peculiar armor used for offense. In addition to the portions of armor above mentioned, there was a pair of small plates just behind the skull, which served to protect this part of the neck. There were also, in the present species, four flat spines, which were probably in place below the tail, but as their position is somewhat in doubt, they are not represented in the present restoration.

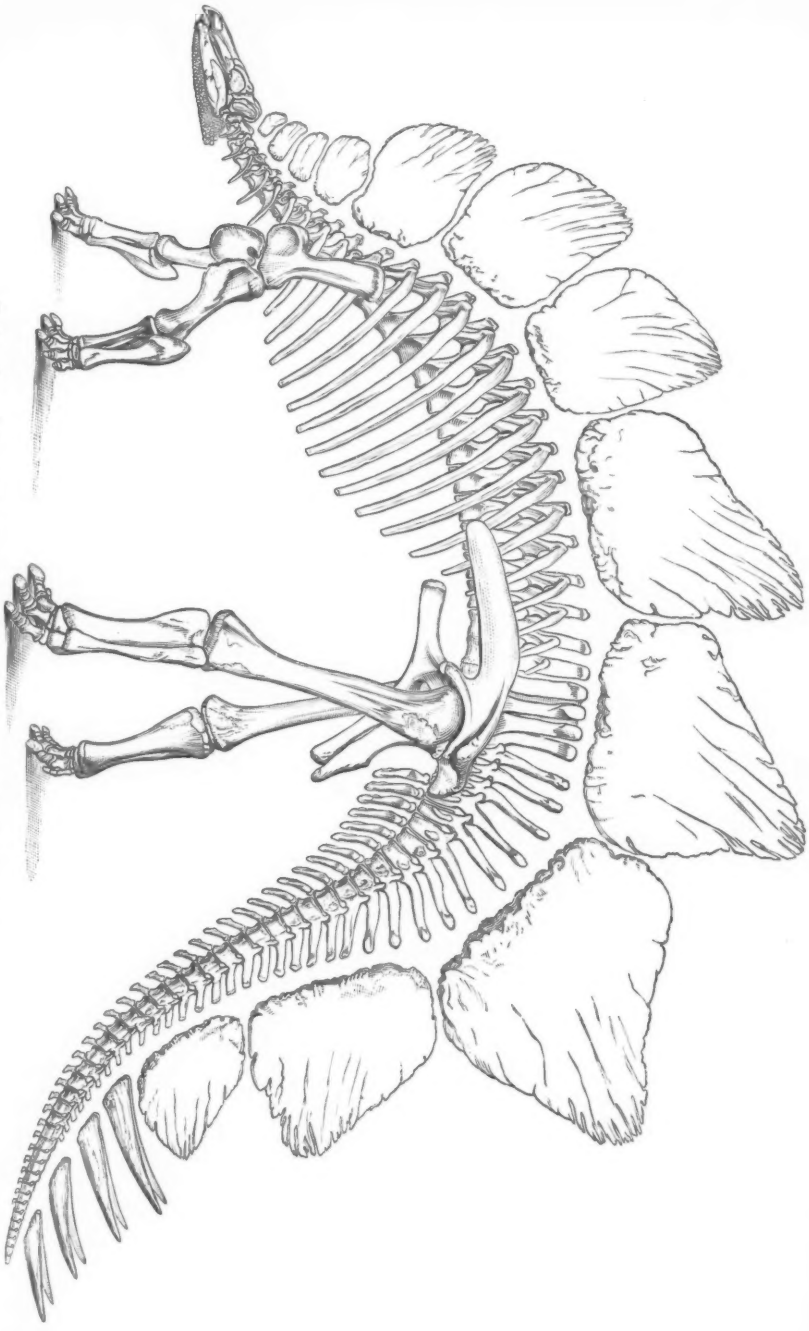
All these plates and spines, massive and powerful as they now are, were in life protected by a thick, horny covering, which must have greatly increased their size and weight. This covering is clearly indicated by the vascular grooves and impressions which mark the surface of both plates and spines, except their bases, which were evidently implanted in the thick skin.

The peculiar group of extinct reptiles named by the writer the *Stegosauria*, of which a typical example is represented in the present restoration, are now so well known, that a more accurate estimate of their relations to other Dinosaurs can be formed than has hitherto been possible. They are evidently a highly specialized sub-order of the great group which has the typical *Ornithopoda* as its most characteristic members, and all doubtless had a common ancestry. Another highly specialized branch of the same great order is seen in the gigantic *Ceratopsia*, of the Cretaceous, which the writer has recently investigated and made known. The skeleton of the latter group presents many interesting points of resemblance to that of the *Stegosauria*, which can hardly be the result of adaptation alone, but the wide difference in the skull and in some other parts indicates that their affinities are remote. A comparison of the present restoration with that of *Triceratops*, recently published by the writer,* will make the contrast between the two forms clearly evident.

All the typical members of the *Stegosauria* are from the Jurassic formation, and the type specimen used in the present restoration was found in Wyoming, in the Atlantosaurus beds of the upper Jurassic. *Diracodon*, a genus nearly allied to *Stegosaurus*, occurs in the same horizon. *Omosaurus* of Owen, from the Jurassic of England, is the nearest European ally now known, but whether it possessed a crest of dermal plates like that of *Stegosaurus* is doubtful, although caudal spines were evidently present.

New Haven, Conn., July 15th, 1891.

* This Journal, vol. xli, p. 339, April, 1891.



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